Astronomy and Astro-Physics.

General Astronomy.

EVOLUTION OF THE DOUBLE-STAR SYTSEMS.*

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Sound cosmogonic speculation begins with Kant, who was the first of modern philosophers to advance a definite mechanical explanation of the formation of the heavenly bodies,† and particularly of the bodies composing the solar system. The views of Kant, however, do not seem to have received much scientific recognition until after Laplace's independent formulation, in more exact mathematical terms,‡ of a similar explanation of the origin of the planetary system, based upon remarkable phenomena observed in the motions of the planets and satellites, and known as the Nebular Hypothesis. Partly on account of the overwhelming§ argument of Laplace in favor of a *natural* or *mechanical* explanation‖ of the origin of the planetary system, and the sound dynamical conceptions underlying the great geometer's hypothesis, and partly on account of the keen interest and speculation arising out of Sir Wm. Herschel's epoch-making investigations of the nebulæ, the Nebular Hypothesis was soon accepted by astronomers as an explanation entitled to scientific belief. The classic researches of Sir John Herschel tended still further to establish confidence in Laplace's view of the nebular origin of the heavenly bodies; but when Lord Rosse's great Reflector showed the discontinuous nature of some of the objects then classed as "nebulæ," the question arose whether, with sufficient power, all "nebulæ" might not be resolved into discrete stars. Fortunately, the invention of the spectroscope about 1860 and Dr.

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* Read before the Chicago Academy of Sciences, Feb. 7th, 1893.
† See Kant's "*Allgemeine Naturgeschichte und Theorie des Himmels*," published in 1755; *Sammtliche Werke*, vol. 1, p. 207.
‡ See "*Systeme du Monde*," *Note VII et Derniere*, p. 498.
§ See Laplace's remarks in the Introduction to his "*Theorie Analytique des Probabilites*," p. LXVII.
‖ Newton regarded the planets as having been set in their orbits by immediate hand of the Deity, and held that the fixed stars had been intentionally placed at such vast distances apart in order that they might not fall upon one another by their mutual gravitation. See his remarks in the "*Scholium Generale*" at the close of the "*Principia*."

Huggins' application of it to the study of the heavenly bodies at once answered this question in the negative, by showing that many of the nebulæ are masses of glowing gas in the process of condensation; and hence it then became a matter of great scientific interest to investigate the formation of the heavenly bodies.

The principle of the conservation of energy and the mechanical theory of heat, which Helmholtz was the first to apply to the nebular contraction of the Sun,* and Lane's researches on condensing gaseous masses,† together with the researches of Sir Wm. Thomson on the Sun's age‡ and heat, have each marked important epochs in the development and confirmation of the Nebular Hypothesis as now maintained and generally accepted by astronomers. The nebular origin of the heavenly bodies being at present generally conceded, the main question of interest relates to the process involved in the development of cosmical *systems*.

The Nebular Hypothesis of Laplace supposes the planets and satellites to be the condensed products of rings successively shed by the contracting nebula which originally contained the matter of the solar system, and this theory of ring-formation has exercised extraordinary influence over the minds of scientific men. Prior to the researches of Professor G. H. Darwin on the origin of the Lunar-Terrestrial System, the theory of ring-formation appears never to have been seriously questioned, at least as respects the planetary evolution. But Professor Darwin's discovery of the exceptional formation of the Moon, and his introduction of the important physical agency of Tidal Friction (which was entirely overlooked by Laplace) necessitated considerable modification of the original Nebular Hypothesis, and constituted perhaps the most important step in scientific cosmogony made during this century. Since Tidal Friction is a necessary adjunct of gravitation wherever systems of fluid bodies exist in a state of relative motion, we perceive that it is a physical agency as universal as gravitation itself, operating more or less powerfully in all the systems of the universe.

It is but proper to state, however, that Professor Darwin's researches on Tidal Friction were applied only to the solar system, in which the conditions are highly unfavorable to the Theory (except in the case of the Earth and Moon), chiefly on account of the relatively small masses of the attendant bodies. In the stel-

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* See the Popular Lecture delivered on the occasion of the Kant Commemoration at Königsberg, Feb. 7th, 1854.
† See "American Journal of Science," July, 1870.
‡ See "Popular Lectures and Addresses" of Sir Wm. Thomson, vol. I. p. 349.

lar systems, where each body is sufficiently large to have a con-
siderable moment of momentum of axial rotation, the secular ef-
fects of Tidal Friction must be of far greater importance, and it
will therefore not be surprising if we find that this physical
agency has played a more prominent part in the development of
such systems than even in the case of the Earth and Moon. It
may be remarked that nearly all the cosmogonic speculations
hitherto promulgated have been advanced with especial reference
to the solar system. For it appears that no systematic investi-
gation of the origin of Double Stars was ever attempted prior to
my own researches, which were begun in an elementary manner
about four years ago.

The first step in the investigation was the collection of a Table
of the best orbits available, which were found to be highly eccen-
tric in comparison with the orbits of the planets and satellites.
It was at once evident that so remarkable and fundamental a
difference could not be overlooked in explaining the origin of the
double stars, and the high eccentricities seemed to point with
overwhelming probability to the operation of some powerful
physical cause which had not left a corresponding impress upon
the orbits of the planetary system. Accordingly, it occurred to
me that the cause which had elongated the double-star orbits
might be the secular gravitational reaction arising from Tidal
Friction in the bodies of the stars—an hypothesis that has been
confirmed by subsequent mathematical research, in which meth-
ods were followed analogous to those employed by Professor G.
H. Darwin in his graphical history of the system of the Earth
and Moon. I had seen no intimation that Tidal Friction could
increase the eccentricity, but soon proved it for the case in which
the tides lag (less than 90°), only to discover afterwards that a
similar result had been reached by Professor Darwin several
years earlier,* though it had not been given any particular prom-
inence, and was apparently but little known; hence the discovery
that Tidal Friction could increase the eccentricity was an inde-
pendent one, since at that time my knowledge of Professor Dar-
win's work was based upon a review† which gave no account of
the secular changes of the eccentricity arising from Tidal Fric-
tion.

In the present discussion of the working of Tidal Friction, we
shall first present some of the secular effects in an elementary

* See Article *Tides, Encyclopædia Britannica*, vol. XXIII, p. 378; also Pro-
fessor Darwin's well-known papers in the *Philosophical Transactions* and *Pro-
ceedings* of the Royal Society from 1878 to 1882.
† Miss Clerke's " History of Astronomy during the 19th Century."

geometrical manner, and at length give a rigorous diagram embodying the graphical history of a double-star system.

Self-luminous bodies, such as the Sun and double stars,* are certainly in a fluid state (the term *fluid* being used in the most general sense) and there is reason to believe that the viscosity or "stiffness" of the fluid is usually small. Therefore the tides raised in such masses by the attraction of foreign bodies will not be confined to the surface (as in the case of the fluid oceans surrounding the nearly rigid Earth), but will extend throughout the whole mass; such tides are termed *bodily* tides, and it is with them that we are here concerned. Now imagine a double-star system, whose components we shall call respectively Helios and Sol,† each of which is of the same order of mass, and same general physical condition as the Sun. Suppose both stars to be spheroids endowed with rotations which are rapid compared to their period of revolution about one another, in the same direction, and about axes nearly perpendicular to the plane of orbital motion.

Let the system be started with the spheroids at a considerable distance apart, so that the attraction of either upon the other becomes practically the same as if the masses were collected at the centres of gravity, and suppose the orbit given a small eccentricity. Then, since the fluid is more or less viscous, the tides raised in either mass by the attraction of the other will lag, and if the viscosity is small the angle of the lag will be only a few degrees. For simplicity we shall now treat the spheroid Sol as having its mass collected at its centre of gravity, and examine the effects on the eccentricity arising from the tidal reaction of Helios; but it must be remembered that in general the whole effect of Tidal Friction in the system of stars will depend upon the aggregate effect of the double tidal reaction arising from the rotations of both bodies—a complication that renders the rigorous investigation in general very difficult.

With Sol thus reduced to a weighted point revolving in the plane of the equator and raising tides in Helios, the tidal configuration will be something like that indicated in Figure *a*.

In the position of the tidal ellipsoid of Helios shown in the figure the whole attraction on Sol does not pass through the center of inertia C (about which Helios rotates), but some point c. The reaction of Sol is equal and opposite, and hence there arises

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* A part of this discussion is reproduced from *Knowledge* of May 1892.

† These names are chosen to fix the attention upon a system composed of two sun-like bodies, such as we find in double-star systems.

a couple (with arm $c\,C$) acting against the rotation of Helios. We may resolve the whole attraction of Helios ($c'c$) into two components, one of which ($c'C$) passes through the centre of inertia C and produces no effect, as it is counteracted by the centrifugal force of the revolving body. The other component ($c'd'$) perpendicular to the radius vector is unbalanced by any opposite force, and hence acting as an accelerating force tends to increase the instantaneous linear velocity, whereby there results an increase in Sol's mean distance.

As the axial rotation of Helios is reduced, Sol is wound off on a spiral whose coils are approximately in the same plane and very close together. To speak mathematically, the *moment of momentum* of the whole system is *constant*,[*] and since the reduc-

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tion of Helios' rotation causes the axial moment of momentum to diminish, it follows that the moment of momentum of orbital motion must augment. In other words, Tidal Friction transfers moment of momentum of axial rotation to moment of momentum of orbital motion, and hence the mean distance must increase.

With these very brief introductory remarks, let us now examine the changes of the eccentricity of the orbit. In the mathematical works on the Tidal Theory it is shown that the tide-generating force varies inversely as the cube of the distance of the tide-raising body. The height of the tide varies directly as the tide-generating force. The couple acting against the rotation of Helios arises from the excess of the attraction of Sol on the

[*] The *energy* of the system, however, is not constant, but continually diminishing, owing to loss of radiant energy.

nearer tidal protuberance above that on the further. Now this
excess is found to vary inversely as the third power of the dis-
tance between the two bodies. But the couple also varies di-
rectly as the height of the protuberance (*i. e.* as the height of the
tide), and this height varies inversely as the third power of the
distance. Hence the Tidal Frictional couple varies as the inverse
sixth power of the distance; or it may be described as varying in-
versely as the square of the tide-generating force, since the tide-
generating force varies inversely as the cube of the distance. If
we denote the Tidal Fractional couple by T, the radius vector by
ρ, the tangential force by t, the principle of action and reaction
gives, for the equilibrium of the forces, $T = t\rho$, or $t = \dfrac{T}{\rho} = \dfrac{\varkappa}{\rho^7}$,
since T varies as $\dfrac{1}{\rho^6}$.

Therefore the tangential disturbing force varies inversely as the
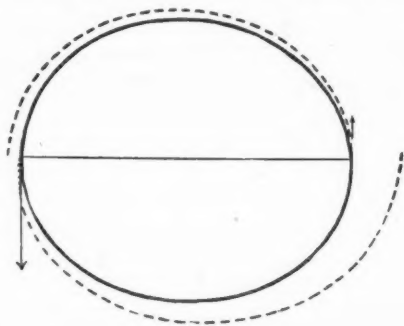seventh power of the distance of the tide-raising body.

FIG. *b.*

When Sol is in perihelion the tides are higher (in the inverse ra-
tio of the cube of the distance) and the tangential disturbing
force is greater than when Sol is in aphelion, in the inverse ratio
of the seventh power of the perihelion and aphelion distances.
It is well known in the theories of planetary motion that a dis-
turbing acceleration at perihelion causes the revolving body to
swing out further than it would otherwise have done, so that
when it comes round to aphelion the distance is increased. In
like manner, an accelerating force at aphelion increases the peri-
helion distance, somewhat as we have roughly shown in Fig. *b.*
Now, if we consider the Tidal Frictional component to act in-
stantaneously and only at the apses of the orbit, the effect would

be to increase the perihelion as well as the aphelion distance, but
the latter at such an abnormally rapid rate that the orbit be-
comes more eccentric.*

If the orbit is not very eccentric similar reasoning to that just
employed for the two apses could be applied to other opposite
points in the orbit, and the same general results would follow;
when, however, the eccentricity is considerable, this method of
procedure is not so satisfactory, though while the tides lag, as
in Fig. *a*, the eccentricity will continue to increase.

We shall now present the effects of Tidal Friction as the con-
verse of those arising from a resisting medium, and shall deter-
mine the law of the density of the medium required to counteract
the effects of Tidal Friction. Let us consider the case in which
the orbit has only a moderate eccentricity (say not surpassing
0.3), since practically the whole disturbing force due to the tides
in Helios may then be regarded as acting in the tangent to the
orbit. When the tides lag (less than 90°, as in Fig. *a*), the tan-
gential component is directed forward, and hence tends to accel-
erate the instantaneous linear velocity; the force arising from a
resisting medium is directed continually backward, and hence
tends to cause the instantaneous linear velocity to diminish.
The two forces are therefore oppositely directed, and hence it is
evident that if they acted simultaneously the orbit would not
undergo the least change either in size or shape, but would be
rigorously stable. Now, the resistance encountered at any given
point of the orbit depends upon the density of the medium, and is
also proportional to the square of the instantaneous linear ve-
locity; but from Kepler's law of equal areas in equal times, it fol-
lows that the momentary velocity of the revolving body varies
inversely as the radius vector. The tangential accelerating force
due to Tidal Friction varies inversely as the seventh power of the
distance; therefore, in order to counterbalance this by a retard-
ing force due to resistance we must suppose the density of the
medium to vary inversely as the fifth power† of the distance from
the centre. Such a medium would give a resistance that would

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* If the eccentricity is to remain constant the increase must be in the ratio of
$(1-e)$ to $(1+e)$; with Tidal Friction the ratio is more nearly $(1-e)^7$ to $(1+e)^7$,
though not rigorously so, except when the eccentricity is very small.

† If σ be the density of the medium, ρ the radius vector, and $\varkappa$ some constant,
then the tangential resistance t' varies as $\varkappa \sigma v^2$, but v^2 varies as $\dfrac{1}{\rho^2}$; therefore t'
varies as $\dfrac{\varkappa \sigma}{\rho^2}$. The tangential disturbing force t varies as $\dfrac{\varkappa}{\rho^7}$, and if t' is to be
made equal to t, we must suppose σ varies as $\dfrac{1}{\rho^5}$. Then $t' = t = \dfrac{\varkappa}{\rho^7}$.

just annul the changes arising from Tidal Friction. Now, Laplace has shown* that the action of a resisting medium increasing in density toward the centre, according to any law whatever, causes the major axis and the eccentricity of the orbit of a revolving body to diminish. Therefore, Tidal Friction must cause the major axis and the eccentricity of the orbit to increase.†

The stellar orbits are on the average about twelve times as eccentric as those of the planets and satellites. The mean eccentricity of the 70 orbits now roughly known is 0.45, while the corresponding mean for the orbits of the eight great planets and their twenty‡ satellites is less than 0.0389. The orbit of γ Virginis is known with great precision, and here we have the remarkable eccentricity of 0.9; and the very trustworthy orbit of Sirius, recently computed by Dr. Auwers, has the very considerable eccentricity of 0.63. From a number of other orbits whose eccentricities are very well determined the fact seems certain that the double-star orbits are generally highly eccentric, though some few appear to be more circular, in accordance with the theory of tidal evolution under what are perhaps rather abnormal conditions. Therefore we have in the general elongation of the double-star orbits a visible trace of the action of secular Tidal Friction, which has played so important a part in the evolution of the stellar systems mainly because of the large mass-ratios of the component bodies, and their comparative proximity during immense ages; for it must be remembered that double-stars, now condensed and widely separated, were millions of years ago much closer together and more expanded in volume, and hence the tidal action was then very much greater than at present.

In the *Inaugural-Dissertation*§ recently presented to the Faculty of the University of Berlin, I have discussed ,with all possible rigor, the working of Tidal Friction in a system composed of two equal fluid spheroids endowed with congruous rotations about axes nearly perpendicular to the plane of orbital motion

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* *Mecanique Celeste. Liv.* X., *Ch.* VII, *Sec.* 18; or Watson's " Theoretical Astronomy," p. 552.
  † We may add that the increase will usually continue until the rotations of both stars are nearly exhausted, after which the eccentricity will be reduced by the libratory motion of the system, and the orbit will at length become circular. The stars, however, would then perhaps be entirely dark, and hence, if in the immensity of space any such dark rigid double-star systems exist, they cannot be observed. Other relations of rotation and revolution, and various other viscosities, give rise to various other results; but the conclusion above reached is that of chief interest in connection with the great multitude of double stars hitherto discovered.
  ‡ Professor Barnard's new satellite of Jupiter is not here included, but the eccentricity of its orbit also is doubtless very small.
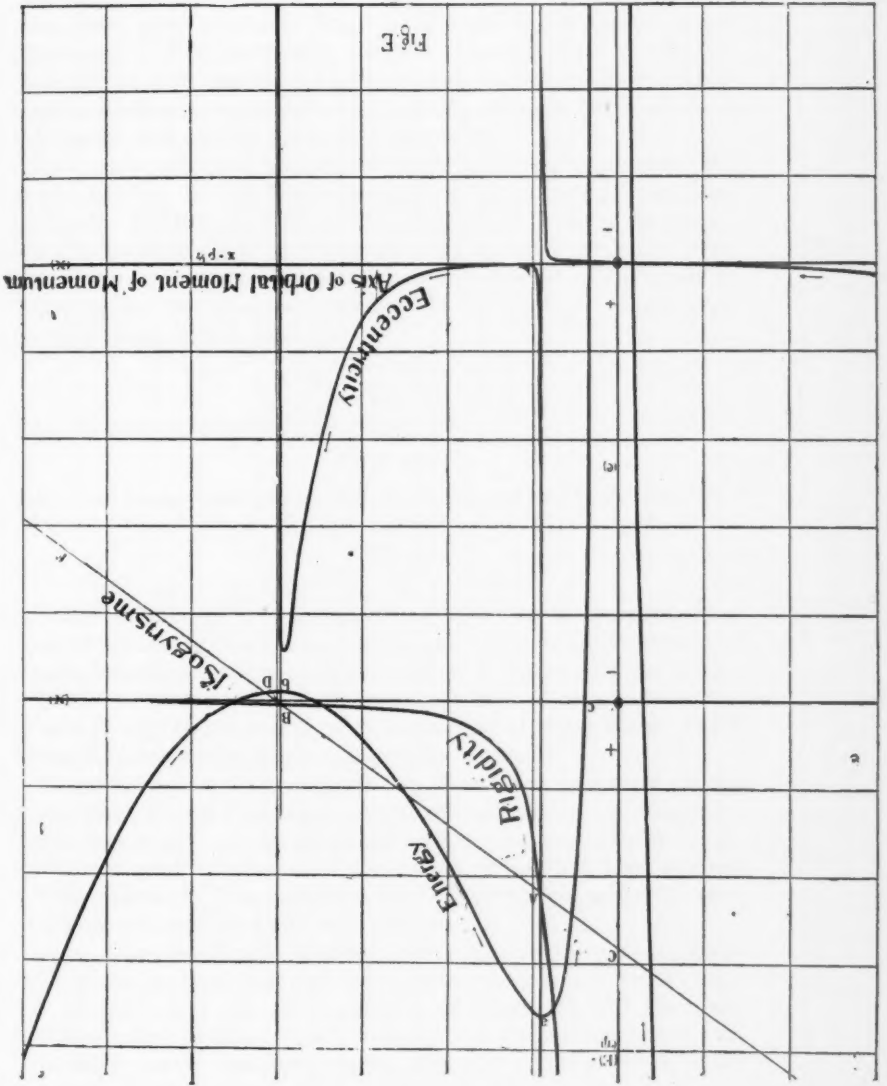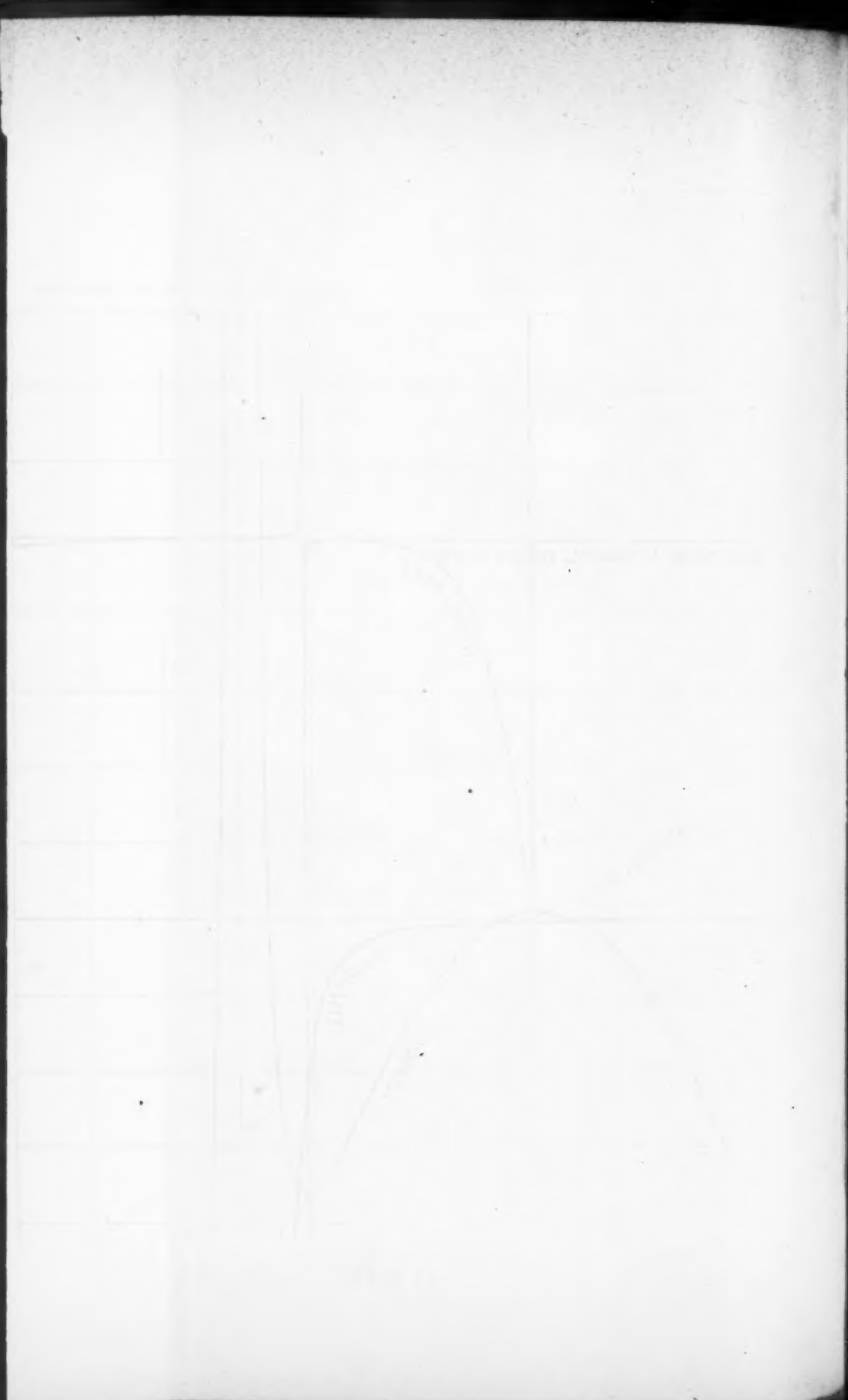 § *Die Entwickelung der Doppelstern-Systeme*, Dec. 10th, 1892.

XUM

Fig E

Axis of Orbital Moment of Momentum

Eccentricity

Isogynisme

Rigidity

Energy

PLATE XX.

and in the same direction as the revolution. Without going into
the details of the research (which is based on Darwinian princi-
ples), it may be added that the problem is completely solved, for
the particular case just mentioned, when the initial velocities of
rotation are equal; and in an investigation not yet published I
have been able to show that the history of the system in all
other cases will be essentially similar. Therefore, the results ar-
rived at in this particular case (where the spheroids are iden-
tical) and directly applicable to a system of equal stars, such as
γ Virginis, will also be applicable generally.

Now, since the system is non-conservative, the energy must de-
grade (owing to the loss of radiant energy arising from tidal
molecular friction), and hence the ordinates of a curve represent-
ing the total energy of the system must decrease with the time.
The rigorous dynamical equations are illustrated in Diagram E,
which gives the graphical history of the system. The energy
curve is given by the equation

$$E = \frac{(H-x)^2}{2} - \frac{1}{x^2},$$

and the curve of Rigidity (Starrheit) by

$$x^3\eta = \sqrt{2},$$

while the Isogyrisme (a line which corresponds to Darwin's "line
of momentum," where only one body rotates) takes the form

$$\eta = \frac{H-x}{\sqrt{2}}.$$

In these equations, x represents the moment of momentum of
orbital motion and is also proportional to the square root of the
mean distance between the two bodies; H represents the whole
moment of momentum of the system, which is constant; E, the
whole energy (both kinetic and potential) of the system, which
must diminish under the action of Tidal Friction.

The three equations just given are illustrated by curves (in the
upper part of the diagram), which are referred to the origin 0'.
In the lower part of the diagram we have the eccentricity curve,
which (to avoid confusion of too many curves) has been referred
to the origin 0. The equation for the eccentricity curve is very
complicated, and need not be given here.

Now, every point on the energy curve represents one configura-
tion of the system (*i. e.* one mean distance, or one orbital angu-
lar velocity, and one axial velocity of rotation) and there are
corresponding points (which have the same abscissas) on the ec-
centricity curve, the Isogyrisme, and the rigidity curve. (We

may remark, however, that the *eccentricity curve* does not give the *absolute*, but only the *relative* fluctuations of the eccentricity.) By the nature of the system, the point on the energy curve, when supposed to represent a configuration of the system, must slide down a slope of the curve, as indicated by the arrows, and resulting changes in the eccentricity are to be interpreted as shown in the figure.

When the bodies are first separated the configuration of the system (which moves nearly as though rigidly connected) is that indicated by the point *a*; the *guiding point* of the system (as we call the point representing the configuration) may here slide down the curve *ac* (in which case the bodies fall together, since *x*—the square root of the mean distance—continually decreases) or it may slide down the slope *ab* (in which case the bodies separate from each other—as actually takes place with systems existing in space). Where the bodies separate, the distance will continue to increase until the rotations of the bodies are exhausted and the system reaches a configuration of minimum energy. We observe that as the bodies recede from each other the eccentricity at first slightly decreases (owing to a sort of libratory motion in the system), and, after passing the minimum value, increases until a high maximum is attained, when the bodies revolve at a great distance from each other and with a long periodic time. Without going further into detail, it may be remarked that the career of the system included in the slope *ab* and the corresponding part of the eccentricity curve appears to be that which is usually fulfilled in nature.

We see therefore that as the mean distance of the bodies increases, the eccentricity also increases and attains a maximum, after which it falls (when the bodies lose their relative motion and begin to move as though rigidly connected—a state which would supervene when the bodies cease to contract).

The eccentricities of the double-star orbits appear therefore to have been *developed* in the course of vast ages, and will in the lapse of thousands of centuries also disappear; but by that time the (dark) systems will have become rigid, so that systems in this state (of minimum energy), if any exist, are necessarily invisible. The orbits of *observed* double stars are therefore highly eccentric, and in this elongation of the orbits we have a visible trace of the working of a physical cause, which, for millions of years, has been changing the size and shape of the orbits.

In order to ascertain whether the action of Tidal Friction could satisfactorily explain the expansion and elongation of the dou-

ble-star orbits, I took an *ideal system* (in default of accurate
knowledge of any *real system*) and derived numerical results
which appear abundantly to confirm the theory.

In this numerical calculation, it was supposed that the two
spheroids were identical homogeneous nebulous masses, each
three times as massive as the Sun, expanded to fill the orbit of
Jupiter, and endowed with an axial rotation such as to give an
oblateness of 0.4. These spheroids were supposed to be placed
at a mutual distance equal to that of Neptune from the Sun, and
set revolving in an orbit with an eccentricity of 0.1. Then, it
was found that as the semi-major axis increased under the action
of Tidal Friction, the eccentricity also increased, and attained a
maximum of 0.57 when the mean distance was 49.388 astro-
nomical units, after which the eccentricity again decreased (ow-
ing to the libratory motion in the system) and vanished when
the minimum of energy was reached at a mean distance of
50.9538 times the distance of the Earth from the Sun. In other
words, Tidal Friction had nearly doubled the semi-major axis of
the orbit, while it had also rendered the eccentricity larger than
the mean eccentricity observed among the double-stars. From
the investigation it also appeared that the maximum eccentricity
attained in a system depended largely upon the initial eccen-
tricity with which the system was started, larger initial eccen-
tricties giving larger maxima for this element.

It appears therefore that the Theory of Tidal Friction abun-
dantly explains the larger as well as the smaller eccentricities,
and it now remains to discuss the process by which a nebula
under accelerating axial rotation splits up into two comparable
masses.

M. Poincaré[*] and Professor Darwin[†] have investigated the
equilibrium of rotating masses of fluid with a view of testing
Laplace's theory of the formation of the planets and satellites.
The researches are widely different in character, but they lead to
substantially the same result, namely: That when equilibrium
breaks down in a rotating mass the portion detached by increas-
ing angular velocity, should bear a far larger ratio to the parent
mass than is observed in the planets and satellites of the solar
system; and, moreover, that while the separation might ideally
take place in the form of a ring, the general process of division
would give rise to masses of a more or less globular form. The
Apioid of M. Poincaré is given in the accompanying figure

[*] *Acta Mathematica*, vol. VII.
[†] *Phil. Trans.*, 1887.

which shows the manner in which the Jacobian ellipsoid under
increasing axial rotation becomes unstable and finally breakes up
into two comparable masses, by a sort of division resembling
"fission" among the Protozoans. That this process of separa-
tion actually occurs in space will be evident on comparing the
Apioid with Sir John Herschel's drawings of double nebulæ,
which are here reproduced. It seems legitimate to conclude that
the double nebulæ have originated from single (perhaps irregular)
masses by the process of "fission" arising from increasing rota-
tion, and that in the course of millions of years they will develop
into double stars.
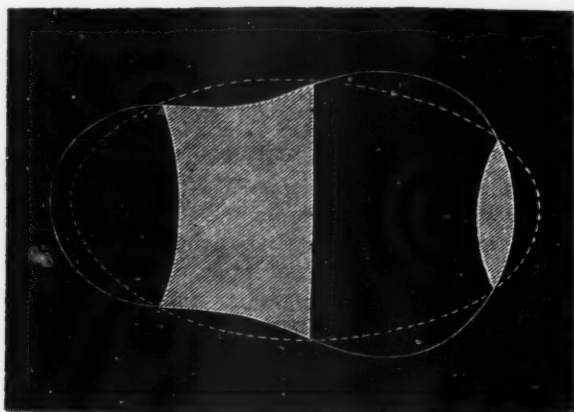
M. POINCAIRÉ'S APIOID.

F Double nebulæ have been greatly neglected since the time of Sir
John Herschel, but it is to be hoped that astronomers will again
give adequate attention to these remarkable objects, which
should be at once systematically studied and photographed. If
accurate drawings or photographs of these objects were now
made, it is not to be doubted that important changes could be
observed 50 years hence.

Should the theory of double-star evolution here briefly and im-
perfectly sketched prove to be substantially true, I think it will
be conceded that it throws considerable new light upon the pro-
blem of the formation of the heavenly bodies. For hitherto
nearly all investigators have proceeded in their researches from
the point of view of the solar system, notwithstanding the fact
that our system is very remarkable, and indeed different in two
respects from any other hitherto discovered:

PLATE XXI.
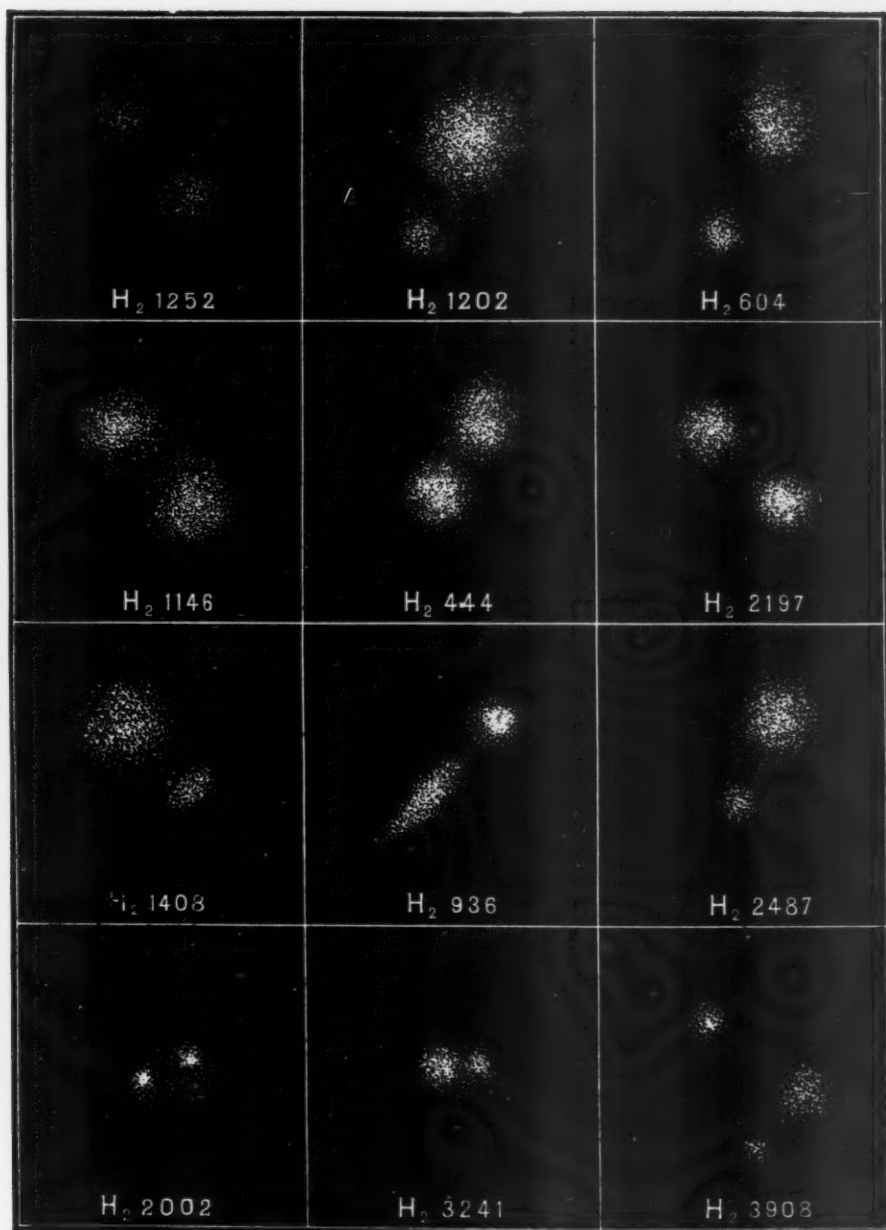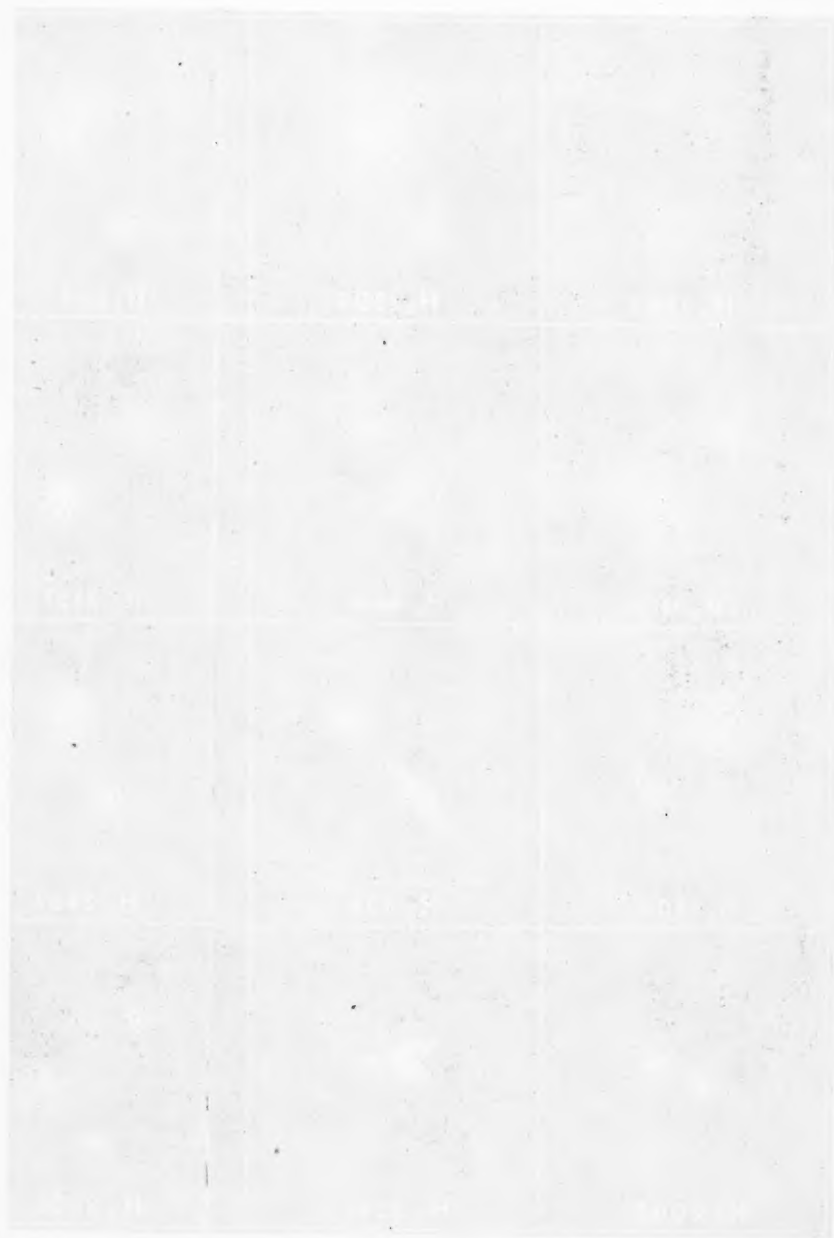
(1). *The revolving bodies are very small relative to the central bodies* (except the Moon whose mass amounts to $\frac{1}{80}$ of the Earth's mass).

(2). *The orbits are nearly circular* (we neglect the asteroids and comets).

The double-star systems are remarkable for:

(1). *The large mass-ratios of the component bodies.*

(2). *The high eccentricities of the orbits.*

It seems hardly credible, and yet it is a fact, that the Sun has 750 times the mass of all the attendant bodies combined; hence we see that practically all the mass of the solar nebula has gone into the Sun. In double-star systems, the masses, if not equal, are at least *comparable*. In other words, *the mass-distribution in the solar system is essentially single, whereas in double-star systems it is essentially double.*

Therefore it is not wonderful that Tidal Friction has played so prominent a part in double-star systems, and has been so unimportant in the solar system, where the masses of the revolving bodies are so small as to render their moments of momentum of axial rotation inefficient in changing the size and shape of the orbits. Considering the exceptional character of our system, are we not therefore justified in affirming that the general law of cosmical development can only be deduced from the study of other systems in space, and especially of double-stars and double nebulæ, which seem to typify the normal form of celestial evolution? If so, the importance of studying double stars and double nebulæ will be the more easily perceived, as will also the interest attaching to multiple stars and clusters, which deserve the most careful study and the most systematic investigation. For if all the clusters now visible in the heavens were carefully studied and measured, by means of Photography, it is not to be doubted that in half a century some progress could be made towards explaining the formation of these wonderful aggregations of stars, concerning which we are at present profoundly ignorant.

If adequate attention is given to other systems in space, we may be sure not only that true cosmonony will be greatly advanced, but that we shall also gain additional light respecting the formation of our own extraordinary system, whose development seems to have been somewhat anomalous.

But even in the case of the solar system, it is questionable whether the theory of ring-formation is applicable, except in the case of Saturn's rings and the asteroids—two formations which are connected by striking analogies and appear to be exceptions

in the planetary evolution. Laplace's theory of ring-formation, although mathematically sound in principle, fails utterly when applied to the actual systems of the Universe at large, as we infer from the well-known rarity of ring nebulæ and the great abundance of double nebulæ and double stars. It is to be remarked, however, that it was not known in the time of Laplace that a rotating mass of fluid could assume any other than symmetrical figures of equilibrium (including, of course, the *annular form*); but from the researches of Poincaré and Darwin we infer that unsymmetrical figures such as we observe in double nebulæ are not only ideally possible, but are in general actually realized in nature. Therefore, since the planets also could have separated in the form of globular masses, there is no longer any logical reason for holding the theory of ring-formation, except in the case of Saturn's rings and the asteroids, which appear to have been exceptional.

There are other nebulæ worthy of study, particularly the spiral nebulæ, but since their true figures remain unknown, they have not been considered in this discussion. If adequate attention is given to double, multiple, and spiral nebulæ, future research will throw light upon problems which now remain obscure, and in the course of time we shall perhaps be able to reach a definite conclusion respecting the formation not only of our own system but of systems generally. And when sufficient data have been collected to throw light upon the results of theory, cosmogony ought to rise from the plane of mere speculation to the rank of a real science. If we shall at present succeed in discovering the law of double-star evolution, no inconsiderable advance will have been made in the right direction.

THE UNIVERSITY OF CHICAGO,
    1893, Feb. 7th.

ON THE RELATIONS WHICH OBTAIN BETWEEN THE MEAN MOTIONS OF JUPITER, SATURN, AND CERTAIN MINOR PLANETS.*

DANIEL KIRKWOOD.

The interesting relations between the mean motions of Jupiter's first three satellites are known to every astronomer. From the date of the first exact observations, these bodies have moved

* Communicated by the author.

in perfect harmony with this remarkable law. But who, without demonstration, would have ventured to affirm it rigidly exact? Laplace proved that if the original motions had *very nearly* these relations, the mutual influence of the satellites would, in time, have rendered them perfectly true. Back of this law, however, remains the unsolved question—Why were the original masses, positions, and motions of the three bodies in question, such that nothing more was necessary than a slight mutual influence to render the phenomena forever permanent?

Now the disturbing effect of Jupiter and Saturn, especially of the former, in the asteroid zone, may obviously have been somewhat similar. Putting

$$n^V = \text{the mean daily motion of Jupiter,}$$
$$n^{VI} = \text{that of Saturn,}$$
$$n^{(279)} = \text{that of Thule,}$$
$$\text{etc., etc.,}$$

we discover special relations at the orbits of commensurability. Thus

$$3n^{(279)} = 4n^V \tag{1}$$

where

$$n^V = 299''.1284$$

and

$$n^{(279)} = 398''.8376 \tag{2}$$
$$n^{(318)} - 3n^{(279)} + 2n^V = 0 \tag{3}$$
$$n^{(318)} = 597''.919 \tag{4*}$$
$$2n^{(153)} = 3n^V \tag{5}$$

where

$$n^{(153)} = 448''.6926 \tag{6}$$
$$2n^{(188)} = 5n^V \tag{7}$$

or,

$$n^{(188)} = 747''.8210 \tag{8}$$
$$n^V - 3n^{(279)} + 2n^{(153)} = 0 \tag{9}$$

and

$$2n^{VI} - 3n^V + n^a = 0 \tag{10}$$

where

$$n^a = 656''.4 \pm$$

or, the critical region indicated in (10) is about the orbits of Adorea 268 and Chryseis 202.

The parts of the system indicated by equations (1) to (10), with their interesting phenomena, suggest fruitful themes for inquiry. It is doubtless impossible to calculate the infinitesimal perturbations of asteroids, but the disturbance of their motions by major planets is a legitimate object of investigation.

RIVERSIDE, California.

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* Berberich's value—Anniuare 1893.

SOME EFFECTS OF A COLLISION BETWEEN TWO ASTEROIDS.*

SEVERINUS J. CORRIGAN.

The motion of particles projected horizontally from the central body or asteroid under discussion, will now be considered. The paths through which they move must, of course, be arcs of some one or other of the conic sections, the form of curve depending upon the velocity of projection.

A velocity which is given by the equation

$$V = k \cdot \sqrt{\frac{2m'}{R}} \tag{7},$$

in which, R, represents the radius of the central body whose diameter is 74 miles, and the other quantities have the signification assigned them on preceeding pages, would throw a particle off in a parabolic curve, while under any greater velocity this particle would describe the arc of a hyperbola, and in either case it would never return to the central body. On the other hand, a less velocity would cause such a particle to move in an elliptical, possibly in a circular orbit, and if the orbit be an ellipse of sufficiently great eccentricity, this particle might move out in practically a straight line, and then fall back toward the center of gravity of the central mass, or asteroid.

With the value of the mass, m', and of the radius, R, of the asteroid aforesaid, it is found, through equation (7) that the initial velocity at and above which a particle endowed therewith, could never return, is 341.2 feet per second.

Let us now suppose that the small dark disc in Fig. 1, represents the central body or nucleus, aforesaid, and that this body is subjected to an impact from another like body moving from right to left.

Then particles projected by this impact, horizontally, from the points, A and B, with the above specified velocity of 341.2 feet per second, will describe parabolic arcs, AC and BC, which may be regarded as limiting lines within which particles cast off by the same force due to the impact, but with a less, or an elliptic, velocity, must be found. The lines AD and BD may, in like manner, be regarded as arcs of a hyperbola, which arcs particles projected with some indefinite velocity greater than parabolic must describe and as limits within which matter whose initial velocity

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* Communicated by the author. Continued from page 212.

lies between the parabolic and the indefinite hyperbolic velocity aforesaid, must move.

An examination of Fig. 1, which has been constructed from purely theoretical deductions from the principles above set forth, will, I think, disclose a remarkable resemblance between that figure and the actual appearance of Holmes' comet as admirably depicted by Dr. H. C. Wilson in No. 111 of ASTRONOMY AND AS-TRO-PHYSICS.

I do not mean that the above depicted diagram is a *fac-simile* but only that it corresponds with his in the relation and significance of the several parts. Thus, the small black disc represents the central body, asteroid, or nucleus, the dotted arrows, the matter projected radially at high (*i. e.* parabolic or hyperbolic)

Fig. 1
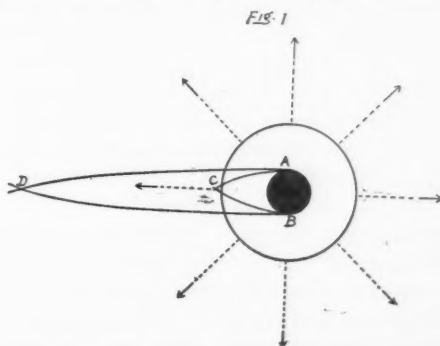
velocity, and dispersing in space under the action of the Sun; the circle represents the condensation around the nucleus, its radius being that of the "sphere of control," which radius has been designated by ρ; the short tail depicted by Dr. Wilson has its counterpart in the matter included between the lines AC and BC, and the long one, by that lying within the lines AD and BD. The whole appearance of the comet thus indicates that that body is the result of a *collision* rather than of an *explosion*, the impact having been caused by a more rapidly moving body approaching from the direction opposite to that indicated by the tails aforesaid. Between Nov. 6, 1892, and Dec. 23 following, the greater "tail" grew to a length of nearly 2°, which would indicate an average velocity for the particles constituting that appendage, amounting to about 7,500 feet per second, a hyperbolic velocity nearly 22 times as great as the parabolic velocity at the nucleus.

The remarkable phenomena exhibited by this comet (or quasi-

comet), on Jan. 16, 1893, and which were witnessed by Dr. Wilson and other astronomers whose descriptions thereof appeared in No. 112 of ASTRONOMY AND ASTRO-PHYSICS, furnish strong evidence in favor of the "collision" hypothesis. In the "Comet Notes" of the aforesaid number, I suggested that this renewed activity and re-illumination was due to the fall and condensation of matter which had been projected from the nucleus on, or a little before, the date of Holmes' discovery. Matter so projected radially, and falling back toward the centre of gravity of the cometary mass, may be regarded as having moved in an elliptic orbit of such great eccentricity that it was practically, a straight line. Now, since whatever may be the eccentricity of the elliptic orbit, Kepler's third law governs the motions of matter revolving therein, the mean distance a of such an orbit can be found through the equation

$$a = \sqrt[3]{m'k^2T^2} \qquad (8)$$

in which T represents the time of revolution, *i. e.*, the time occupied by a particle in going out to the extreme limit of its path or to the outer apsis of the elliptic orbit, and returning to the centre of gravity of the cometary mass.

If the matter left the central body on the occasion of the first appearance of the comet, or shortly before the date of discovery, on Nov. 5th, 1892, for instance, and returned on Jan. 16th, 1893, the value of T would be 72 days. With this value and those of the other quantities in the second member of equation (8), which are known, the mean distance a is found to be 4,289 miles, and twice this, or 8,578 miles, is the distance to which this matter must have been projected by the impulse due to the collision.

The limit of the "sphere of control," or ρ is, as has been determined above, about 25,000 miles, so that the mass of *debris* under consideration was hurled to only a little more than ⅓ of that height; this is what would naturally occur, because it is probable that, judging by the effects observed on Jan. 16th, this mass was composed of the larger ejected particles, whose initial velocity was less than that of the smaller particles, or finely divided matter, comparable to dust, which therefore rose to greater heights up to the limit of 25,000 miles. Now let us note the probable movements of such a mass of matter so projected and the effects produced thereby. After rising to the height of 8,578 miles in 36 days, it would begin its descent. Scattered in space at that height, it would not be at all conspicuous, unless it were in very great quantity, but as it neared the centre of gravity, or

the nucleus, about Jan. 16th, 1893, the concentration of this mat-
ter in a comparatively limited space would increase the brilliancy
of the apparent nucleus by an amount directly dependent upon
the surface which this condensed matter would present. If we
suppose the particles to have been in such numbers, or of such
size, that when near the nucleus, they presented a solid surface,
or disc, about 400 miles in diameter, or equal in this dimension
to Vesta, the application of equation (6) would give the magni-
tude of the apparent nucleus, supposing its luminosity to be due
to reflected light only. The last term of the second member of
that equation would, under these conditions, become zero, and
the resulting magnitude for Jan. 16th would have been 7.5.
Now, although it is not known whether the falling matter under
consideration was sufficient in quantity to produce the apparent
disc 400 miles in diameter, or otherwise, it is interesting to note
that on the above named date, Dr. Wilson of "Goodsell Observa-
tory" described ("Comet Notes," A. and A.-P., No. 112) the nu-
cleus as "at first hazy, afterwards more star like, and about as
bright as an 8 mag. star." Professor Barnard of "Lick Observa-
tory" estimated it, at the same time, as of the 7.5 or 8 magni-
tude.

Matter thus falling would, for a long time, move very slowly,
but as it neared the nucleus, the action must have been greatly
accelerated, causing the apparent nucleus to seemingly enlarge,
and to brighten greatly in a remarkably short time, while the il-
lumination of the surrounding finely divided matter, or dust
would cause the comet to apparently increase in size in a remark-
ably rapid and unaccountable manner. Shortly afterward, or so
soon as all the falling matter reached its original position on the
nucleus, the brightness of the latter would fall to the normal
magnitude due to the surface presented by the central body whose
dimensions were given on a preceding page.

The clashing of the falling particles as their motions were
arrested, must have resulted in the projection of finely divided
matter, or dust, and therefore, in the repetition, on a smaller
scale, of the phenomenon of "expansion" of the comet, which
was so notable a feature of that body shortly after its discovery.

Now, all of these probable effects were actually observed by Dr.
Wilson, Professor Barnard and other astronomers, on Jan. 16,
1893, and I believe, therefore, that these observers caught sight
of the falling matter very nearly at the time that it reached the
nucleus, central body or asteroid.

In considering the heating effects produced by such falling

matter, I obtained a rather surprising result: As is well known,
if the velocity of a moving mass be arrested, and no mechanical
effects be produced thereby, the kinetic energy of such mass will
be converted into heat, and t, or the number of degrees Fahr., by
which any mass of weight, w, would be heated up by reason of
such arrested motion, is given by the equation,

$$t = \frac{2wv^2}{100,000s} \tag{9}$$

in which v is the velocity, in feet per second, and s the "specific
heat" of the substance. If we take the "specific heat" of
the matter under consideration as equal to that of the
metals of the iron group, or about 0.1, we will probably be very
near the truth, in any case sufficiently near for the present pur-
pose. The maximum initial velocity of projection of matter
ejected from and returning to the nucleus was found through
equation (7) to be about 341 feet per second, and this may be taken
as the maximum velocity with which the falling matter could
strike the surface of the central body. With this as the value of v,
in equation (9), and taking w as one pound, I find that the tem-
perature by which that pound of matter would be raised by such
a fall, would be only 23° Fahr. Now, since small masses of
matter out in space and devoid of atmospheric envelopes, have
probably nearly the temperature of the surrounding "ether"
(which temperature is now considered to be not far above abso-
lute zero, or − 459° Fahr.) it follows that, since to raise such
matter to even a red heat, the augmentation of temperature
must be about 1459° Fahr., the small increase aforesaid gene-
rated by the fall, is practically *nil*, and the illumination of the
cometary matter could not have been due to high temperature.
If the heat generated could have been concentrated in a very
small portion of each pound of matter, a sufficiently small por-
tion might have been raised to the temperature of incandescence,
but by conduction and radiation even that portion of the matter
would have cooled almost instantaneously. Therefore in so far
as this source is concerned, the conclusion arrived at, and which
seem to have been confirmed by the spectroscope, is that the
light of the comet was reflected light, and that the great increase
therein observed on January 16th, 1893, was due simply to the
greater surface presented by the concentration of the falling
matter around the nucleus, from which matter the light was
reflected.

The heating effects due to the original collision could also be

found if we knew the velocity of each of the colliding bodies at the moment of the catastrophe, on November 5, 1892, for instance. But while the velocities of these bodies are unknown, the probable maximum effect may be determined by finding the greatest and the least velocity possible at any point, for known asteroids having a common radius-vector, which they must have if in collision, and supposing that the orbits are such that these bodies could collide.

The linear velocity of any member of the "solar system," when at any distance, r, from the Sun, is given by the equation

$$V = k.\sqrt{\frac{2}{r} - \frac{1}{a}} \qquad (10)$$

For any given value of r it depends therefore only on the value of a, or the mean distance of the planetary body. Now among 311 asteroids examined "Thule" (279) has the greatest mean distance, nearly 4.26253, and "Sita" (244) the least, which is about 2.17460, while r, or the radius-vector of the "comet" or of the combined bodies in collision was, on November 5, 1892, about 2.38885. With these values in equation (10), the velocity of "Thule" is found to be, for a radius-vector equal to that above given, about 75,000 feet per second, and that of "Sita" nearly 60,000 feet, and the difference is the greatest relative linear velocity possible, at the given distance, r, so far as the same can be determined from the *known* asteroids having the greatest difference of mean distance. The bodies aforesaid could not come into collision at that distance, but are simply used to show the maximum limitation of relative velocity among the members of the system to which they belong. This maximum relative velocity of about 15,000 feet is, most probably, much greater than the actual relative velocity of the colliding bodies. On a preceding page it has been stated that the particles forming the longer "tail" of Holmes' comet must have moved with a mean velocity of about 7,500 feet per second. Now since, acccording to the "collision hypothesis, this tail was composed of particles originally belonging to the more rapidly moving body, and of some cast off, by the impact, from one moving more slowly, it is interesting to note that the relative velocity of such particles lies well within the maximum limit aforesaid, being just one-half thereof. I do not pretend to say, at present, how much value should be attached to this fact, but I think that it may eventually throw some light on the subject, and add something to the strength of the "collision" hypothesis.

We can obtain an approximate knowledge of the effects of impact in altering the respective linear velocities of the two bodies, and, therefore, also the heating effects resulting from such impact through a consideration of the following equations of analytical mechanics. The linear velocities, v_1 and v_2, of two spherical bodies of mass m_1 and m_2, after impact, can be found through the following group of equations numbered (11)

$$\left. \begin{aligned} v_1 &= \sqrt{\left[(1+c) \cdot \frac{m_1 V_1 \cos \varphi_1 + m_2 V_2 \cos \varphi_2}{m_1 + m_2} - c V_1 \cos \varphi_1 \right]^2 + V_1^2 \sin^2 \varphi_1} \\ v_2 &= \sqrt{\left[(1+c) \cdot \frac{m_1 V_1 \cos \varphi_1 + m_2 V_2 \cos \varphi_2}{m_1 + m_2} - c V_2 \cos \varphi_2 \right]^2 + V_2^2 \sin^2 \varphi_2} \end{aligned} \right\}$$

V_1 and V_2 being the original linear velocities, and φ_1 and φ_2 the angles which the directions of the respective motions make with the normal at the point of impact. In these equations c represents the coefficient of elasticity, being 1 for a *perfectly* elastic body, were there any such, and o for a non-elastic one did such a body exist. In the case of perfect elasticity there would be simply a transference of velocities and, therefore, no transmutation of kenetic energy into heat. But by assuming the bodies to be non-elastic, or that c is equal to zero we can obtain the maximum effect, which is the object of this discussion. Moreover since the observations indicate that the bodies were ruptured by the collision, this assumption of non-elasticity will give results nearer the truth than would any other. Furthermore, the masses of colliding bodies may be regarded as equal and by assigning to m_1 and m_2, each, the value of one pound, the final results will be the same as if the actual weight of each body were used. Under these conditions the equations (11) reduce to the following:

$$\left. \begin{aligned} v_1 &= \sqrt{\left(\frac{V_1 \cos \varphi_1 + V_2 \cos \varphi_2}{2} \right)^2 + V_1^2 \sin^2 \varphi_1} \\ v_2 &= \sqrt{\left(\frac{V_1 \cos \varphi_1 + V_2 \cos \varphi_2}{2} \right)^2 + V_2^2 \sin^2 \varphi_2} \end{aligned} \right\} \qquad (12)$$

If, now, we assume that the impact is "direct and central," as in Fig. 2, the angles φ_1 and φ_2 become each, zero, and we have simply:

$$\left. \begin{aligned} v_1 &= \frac{V_1 + V_2}{2} \\ v_2 &= \frac{V_1 + V_2}{2} \end{aligned} \right\} \qquad (13)$$

As has been found above, the minimum and maximum values of

V_1 and V_2 are 60,000 feet and 75,000 feet per second, respectively, the relative linear velocity being thus 15,000 feet per second, if the impact be "direct and central." This is, of course, much greater, probably, than would exist. In fact, if we regard the growth of the larger "tail," above refered to, as indicating the relative velocity, the latter would be only about 7,500 feet per second. Therefore, if we take V_1 as 64,000 feet per second and V_2 as 71,000 feet, the results will be much nearer the truth. Using these in equation (13) for the case of a "direct and central" impact as in Fig. 2, the values of v_1 and v_2 are found to be equal, and each 67,500 feet per second. If the impact were *oblique*, as shown in Fig. 3 ˙(and this is more likely to be the case), the velocities after collision must be found through equations (12), and we may take the angle φ_1 as zero, as before, while the orbits

FIG. 2   FIG. 3
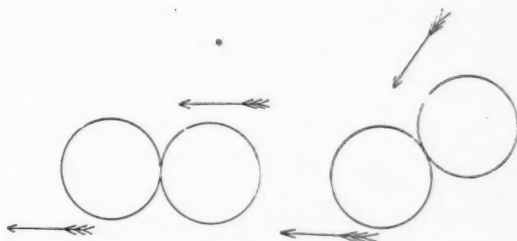
of the known asteroids are such that the angle φ_2 cannot be much greater than 20°. The value of v_1 is then found to be 65,359 feet per second, and that of v_2, 69,724 feet in the same time. The *kinetic energy* of a mass m, moving with a linear velocity v, being, "$\frac{1}{2} mv^2$," we can find the amount thereof for the velocities of the moving bodies prior to the collision, and then that for their respective velocities after the impact, and if the latter be less than the former, the difference will be the quantity of *kinetic energy*, either converted into heat, or used in the work of rupturing the bodies and impelling the resulting particles in divers directions. The application of the above equations gives, in the first case, a loss of *kinetic energy* amounting to 12,250,000 foot-pounds and the effect of this in raising the temperature by an amount t (if there be no other effects) will be given by,

$$t = \frac{mv^2}{50,000s} \qquad (14)$$

s being the "specific heat" whose value has been given on a pre-

ceding page. The value of the rise of temperature for "direct and central" impact as shown in Fig. 2 is found to be nearly 4900° Fahr. But if the impact be *oblique*, as depicted in Fig. 3, the loss of kinetic energy will be much less, being only about 1,860,000 foot-pounds, which would cause a rise of temperature of only 744° Fahr.

Now these two cases are extremes between which the actual case probably lies, and therefore the mean of the values above given, or 2822° Fahr., is the most probable under the supposition that there is no conversion of the kinetic energy into other than *thermic* effects. But since a portion (probably very large) of this energy must have been used in the work of rupture of the bodies, and the dispersion of their resulting particles, even this last named amount is most probably too great.

Moreover, the impact was more likely to be *eccentric* than it was to be *central*, a fact which would still farther reduce the augmentation of temperature. Now since the condition of self-illuminosity requires in this case, an increase of temperature of at least 1500° Fahr., while nearly 2600° Fahr. would be required to raise the matter to "white" heat, the conclusion to which we are led is that while it is barely possible that the body discovered by Holmes could have shone by its own light near the time of its first appearance, rapid radiation of heat must have caused it to soon lose its self-luminosity, and it is more likely that it shone only by reflected sunlight.

In the above discussion two bodies of one pound each have been considered, but if we wish to regard the weight of the whole amount of matter, so far as the same has been determined from the mass as found by the process given in the first part of this article, we can do so by considering the fact that the weight of the Earth is very approximately 13½ septillions of pounds and, therefore, since the mass of the nucleus according to the determination aforesaid, was $\frac{1}{1238975}$ that of the Earth, the weight thereof must have been 10,896,100,000,000,000,000 pounds, one-half of which would be the weight of each of the equal hypothetical bodies in collision.

In closing this article I would say that. as the title thereof indicates, this subject has been viewed from a *purely theoretical* standpoint and that, whether Holmes' comet is the result of a collision between two asteroids or not, such a collision would produce the results which I have above set forth.

But while I do not wish to attach any undue weight to the several agreements between theory and observation which a

study of this subject has disclosed, I think that it is highly improbable, even well nigh impossible, that these agreements could be due merely to a fortuitous concatenation of circumstances. As is well known, the fact of the agreement or disagreement, between theory and observation is the principal "criterion" by which hypotheses are to be accepted, or rejected, even the great theory of "universal gravitation" having to stand, as it does firmly, upon this foundation.

I think, therefore, that since, in so far as I have been able to learn, the observed phenomena of Holmes' discovery are all explicable by the "collision" hypothesis, this hypothesis has a sufficiently firm foundation upon which to stand. It may be here remarked that the principles upon which the above discussion is mainly founded, are the same as those upon which the famous problem of "the three bodies" is based, the bodies in this case being the "nucleus" of the comet, the Sun, and any one of the particles projected from the nucleus aforesaid. The principal results of the discussion set forth in this article have therefore been derived by means of the application of one of the most general and beautiful principles founded upon the great "Law of Universal Gravitation."

St. Paul, Minnesota, February 1893.

DIMENSIONS OF SMALL PLANETS.[*]

D. P. TODD.

Though not regarded as a matter of astronomical significance, the dimensions of small planets have an element of interest. The late Dr. Peters of Clinton calculated the size and superficial area of nearly all those bodies discovered by himself; and while they have been printed in all the recent catalogues of Hamilton College, I have not seen them elsewhere. They are worth a fuller astronomical circulation; and for completeness I have added to Dr. Peters' data in the following table the values of g and m_0 for these bodies from the *Berlier Astronomisches Jahrbuch* für 1894, g and m_0 having the following relations to M,

$$g = m_0 - 5 \log a(a - 1)$$
$$M = g + 5(\log \varDelta + \log r),$$

and the symbols having their usual significations.

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[*] Communicated by the author.

Dimensions of the 48 Small Planets Discovered by Peters at the Litchfield Observatory of Hamilton College, Clinton, New York.

No.	Name.	m_0	g	Diameter in Miles.	Surface in Sq. Miles.	Date of Discovery.
72	Feronia	11.2	8.9	24.9	1950	29 May 1861
75	Eurydice	11.6	8.4	31.4	3090	22 Sept. 1862
77	Frigga	11 1	7.9	39.5	4898	12 Nov. 1862
85	Io	10.9	7.7	43 3	5888	19 Sept. 1865
88	Thisbe	10.8	7.4	49.7	7762	15 June 1866
92	Undina	10.9	6.7	68.6	14790	7 July 1867
98	Ianthe	11.6	8.3	32.8	3388	18 April 1868
102	Miriam	12.6	9.4	19.8	1230	22 Aug. 1868
109	Felicitas	12 0	8.7	27.3	2344	9 Oct. 1869
111	Ate	11.3	8.2	34.4	3715	15 Aug. 1870
112	Iphigenia	11.5	8.8	26.1	2138	19 Sept. 1870
114	Cassandra	11.1	7.8	41.3	5370	23 July 1871
116	Sirona	10.7	7.3	52.0	8511	8 Sept. 1871
122	Gerda	11.5	7.2	54 5	9332	31 July 1872
123	Brunhilda	11.8	8.5	30.0	2818	31 July 1872
124	Alceste	10.3	7.1	57.1	10233	23 Aug. 1872
129	Antigone	10 3	6.6	71.8	16218	6 Feb. 1873
130	Electra	10.6	6.5	75 2	17783	17 Feb. 1873
131	Vala	12.2	9.5	22.7	1622	25 May 1873
135	Hertha	10.5	7.8	41.3	5370	18 Feb. 1874
144	Vibilia	10 7	7.5	47.5	7080	3 June 1875
145	Adeona	11.3	8.1	39.5	4898	3 June 1875
160	Una	11.8	8.4	31.4	3090	20 Feb. 1876
165	Loreley	11.1	7.0	59.6	11220	9 Aug. 1876
166	Rhodope	12.5	9.2	21.7	1479	15 Aug. 1876
167	Urda	13.0	9.4	22.7	1622	28 Aug. 1876
176	Idunna	12.1	7.9	37.7	4467	14 Oct. 1877
185	Eunice	10.4	7.0	59.6	11220	1 Mar. 1878
188	Menippe	13.0	9.4	19.8	1230	18 June 1878
189	Phthia	11.5	8.8	28.6	2570	9 Sept. 1878
190	Ismene	12.0	6.7	68.6	14790	22 Sept. 1878
191	Kolga	12.0	8.3	37.7	4467	30 Sept. 1878
194	Procne	10.5	7.4	47.5	7080	21 Mar. 1879
196	Philomela	10.3	6.3	82.5	21380	14 May 1879
199	Byblis	12.4	8.2	39.5	4898	9 July 1879
200	Dynamene	11.0	7.6	45.3	6456	27 July 1879
202	Chryseis	10.7	6.7	68.6	14791	11 Sept. 1879
203	Pompeia	11.7	8 3	31.4	3090	25 Sept. 1879
206	Hersilia	12.0	8.6	—	—	13 Oct. 1879
209	Dido	11.6	7.5	54.5	9332	22 Oct. 1879
213	Lilæa	11.7	8 3	32.8	3388	16 Feb. 1880
234	Barbara	11.7	9.1	—	—	12 Aug. 1883
249	Ilse	13 6	11.1	—	—	17 Aug. 1885
259	Aletheia	12.1	8.0	—	—	28 June 1886
261	Prymno	11.9	9.4	—	—	31 Oct. 1886
264	Libussa	12.1	8.6	—	—	17 Dec. 1886
270	Anahita	11.0	8.9	—	—	8 Oct. 1887
287	Nephthys	10.7 .	8.2	—	—	25 Aug. 1889

The diameters of (1) to (71) are given by Stone in M. N. R. A. S. XXVII (1867) p. 302, and in Houzeau's *Vade Mecum de l'Astronomie.* p. 638.

THE NEGLECTED FIELD OF FUNDAMENTAL ASTRONOMY.*

J. R. EASTMAN.

With double threads it is possible to observe the zenith distances of such stars with a fair degree of precision, because the operation is one of comparative deliberation and the center of the mass of light can be placed midway between the threads with little difficulty. But the attempt to note with a chronograph key, the instant when a swiftly moving and irregular mass of light, like α Canis Majoris or α Lyræ, is bisected by a transit thread, is an operation that rises but little above the level of ordinary guesswork. Transits of first and second magnitude stars cannot be observed with an objective of more than four inches aperture, with the desired accuracy, unless the apparent magnitude is reduced, by means of screens, to that of a fourth or fifth magnitude star. It is necessary in this connection to avoid confounding the methods employed in the observations of the bodies of the solar system with those for obtaining fundamental places of the stars. The observations of the Sun, Moon, Mercury and Venus with a transit circle are, from the unavoidable conditions, necessarily uncertain to a degree even beyond the probable error involved in the observations of the large stars. In spite of these unfavorable conditions, however, the continued observations of these bodies at the principal observatories, for many years, have produced the most valuable results even when the work on the standard stars, on which their results depend, has no claim whatever to a fundamental character.

In geographic exploration the first endeavor is to secure approximate positions of salient points from a rapid reconnoissance. This is followed by more careful work fixing the observing stations with that degree of precision which insures good results. Finally, the highest qualities of skill and science are combined to exhaust all available means to reach the greatest attainable accuracy. In the exploration of the heavens, the first two of these steps have already been taken, and most of the stars of the larger magnitudes have been so well observed, that the accuracy of their positions is not only far higher than is required by the greatest skill of the navigator, but it is equal to all the demands of ordinary practical work. It is the next step which challenges the skill of the mechanician, the observer and the computer; and astronomers cannot rest at ease until all known resources have

been exhausted in the attempt to reach the best results. It is not a very difficult matter to fix the position of stars within a range, in the individual observations, of three or four seconds of arc, but that degree of accuracy is not sufficient for the more exact problems of astronomy, and it falls far short of what is required in the important discussions of solar and stellar motions.

Bradley's observations furnished the data for Bessel's Fundamenta Astronomiæ and many astronomers have since attempted by reductions to obtain improved positions for Bradley's stars. The value of these observations in the development of modern astronomy can hardly be exaggerated. Their importance in the determination of stellar proper motions increases with the lapse of time; and yet, the accuracy of the original observations was far inferior to that obtained in ordinary routine work with modern methods and improved instruments.

Fundamental Catalogues of stars have notably increased since the Fundamenta Astronomiæ, but the demand has not yet been satisfied. The catalogues of declinations or north-polar distances are more numerous than those of right ascension, evidently because, for many reasons, independent declinations are more readily determined.

There is probably no collection of the right ascension of the large stars that has attained, or justly deserved, a higher reputation than the Pulkowa Catalogue. The observations on which this catalogue is founded were made by Schweizer, Fuss, Lindhagen and Wagner, at the Pulkowa observatory between 1842 and 1853. The observations were reduced by the several observers, thoroughly discussed by Wagner and published in 1869. Only one observer was employed at any period. As these results have received high praise for their accuracy and for their freedom from systematic errors, it may be of some interest to consider briefly, and in a general way, the character of the data on which the results depend.

The objective of the transit instrument with which these observations were made, had a focal length of 8 feet and 6 inches and a diameter of 5.85 inches. It was so constructed that the ocular and the objective could be interchanged. It was also reversible, and a part of the observations were made with the clamp east and the remainder with the clamp west. This construction permitted the observations to be made under four different sets of conditions, and for that reason the observed right ascensions of each star were arranged, for facility of discussion, in four separate groups.

An examination of the results in each group discloses some interesting facts that are worth considering somewhat in detail. The whole number of stars in the catalogue that are reckoned as standard stars, and are south of 70° north declination, is 365. Of this number seventy per cent have a range, in the individual results, in at least one of the four groups, of two-tenths, or more, of a second of time. This range is between $0^s.20$ and $0^s.29$ for 142 stars; between $0^s.30$ and $0^s.39$ for 92 stars; between $0^s.40$ and $0^s.49$ for 15 stars, and $0^s.50$ or more for 6 stars. The mean range for the 255 stars is $0^s.297$. In general, the accordance between the individual results is quite good but the discordance just mentioned sometimes occurs more than once in the collected observations of the same star, and these doubtful data have been used in deducing the standard places given in the catalogue. It is not necessary to look for minor discrepancies, for enough of appreciable magnitude have been cited already to warrant the conclusion that better observing can, and ought to be done with modern instruments and that the needs of astronomical science to-day demand a more comprehensive, and a more accurate, standard catalogue of right ascensions.

These remarks must not be interpreted as unfavorable criticism of the Pulkowa catalogue, by far the best work of its period, but they are made simply to call attention to the fact, that the present state of stellar astronomy and the direction which the investigations of the immediate future are likely to take, plainly require the most accurate fundamental catalogue of the standard stars that modern instruments and appliances, modern methods and the most skilful observers can produce. All of these conditions are essential and they must be carefully coördinated to obtain the desired results.

It must be plain to every astronomer that the needed fundamental catalogue must be deduced from new observations. The reduction and discussion of old observations of doubtful quality are a waste of time and energy. Under existing circumstances the greatest weight must be given to the observations. Neither amount of labor nor skill in computation can derive results of the desired accuracy from careless, incomplete or incorrect observations. An attempt on the part of the computer to apply any system of theoretical weights, either simple or complex, to such observations is almost certain to lead, at least, to self deception; and the safe as well as reasonable rule in such case would be to use the weight zero.

One example may serve to illustrate the effect of dealing contin-

uously with old observations. In standard star positions the
four principal national ephemerides are not only not in accord
with each other, but they generally do not exhibit results, even
from the few best modern observations. The many discrepan-
cies, of varying magnitude, in these volumes, present with marked
emphasis the undesirable results arising from the custom of
" threshing old straw."

The data on which these several ephemerides are founded are
the common property of all astronomers, and no one can claim
the exclusive use of any published observations; and yet national
pride or national obstinacy, which is sometimes mistaken for the
nobler sentiment, or some computer's pet scheme or system of
combination, has led to the adoption of a variety of assumptions
in the interpretation and treatment of the original data, until
our standard ephemerides are so complex in their structure that
the exact details of their preparation are practically unknown
outside their respective computing offices. The accuracy of the
star positions is unchecked by any recent fundamental observa-
tions, and they lack that trustworthy character that should in-
here in a system intended to serve as a basis for even good differ-
ential work.

If this character were wholly satisfactory, we should soon see
the representatives of Astronomy, Geodesy and Geology gather-
ing about the zenith telescope, confident of reaching, by the sys-
tematic use of this simple instrument, some definite conclusion in
regard to the variation of terrestrial latitudes. But the accurate
star positions do not exist, and under the present conditions the
most feasible plan for utilizing this instrument is to arrange the
observing stations so as to eliminate the effect of errors in the
star places.

If it be admitted that sidereal astronomy is worthy of further
and more accurate study, that the needs of astronomical research
at the present time and in the immediate future demand more ex-
act positions of the standard stars, it may be desirable to con-
sider briefly the status of those agencies to which we must look
for the successful prosecution of such an investigation.

POSSIBILITIES OF THE TELESCOPE.*

ALVAN G. CLARK.

A question sometimes asked is: "Will not a great increase in the size of lenses necessitate so much increase in thickness that a large amount of light will be lost by absorption?" In reply, I would say, that we are a long way from experiencing anything very serious in this respect. The forty inch discs, already mentioned, have only a combined thickness of some four inches, and the lenses of an object-glass of even six feet aperture would necessitate a combined thickness of not more than six inches. To be sure this increased thickness means some more absorption, but not to the extent that some suppose, especially with the best glass now obtainable.

An experiment made at my manufactory will perhaps best illustrate just what I mean. I took a block of dense flint glass nine inches thick and polished on both edges. Behind this was placed common newspaper print, while in front of it sat a party who ordinarily, although not invariably, used glasses in reading. Through this nine inches of dense glass, however, he was able with perfect ease to read the whole newspaper article by lamplight, and without optical aid. But this nine inches in thickness is, as I have already said, much more than is necessary for even a six foot lens, and who knows how soon still more transparent glass may be at hand, considering the steady improvement made in this line, and the fact that the present discs are infinitely superior to the early ones.

But even supposing a slightly larger per cent of light is lost by absorption per unit of surface in a six foot lens than in a three foot one, yet the area of the larger will be four times that of the smaller, so that the total amount of light must be vastly greater.

Besides, everyone who has had experience in using telescopes knows that even if two instruments of quite different sizes can both see the same object without trouble, the larger one has a decided advantage from the greater amount of light and the consequent increased ease and facility of seeing, which enables us to do better work. In illustration of the great light-collecting power of a large telescope, I may cite the fact that with the thirty-six inch refractor, eighteen nebulæ were discovered at the Lick Observatory in a space only 16′ by 5′.5, and more recently, a fifth satellite has been added to the planet Jupiter.

As regards the possible bending of great lenses under their own weight, although this sometimes occurs in a small degree, both sides are affected in a nearly compensatory manner, while in a mirror there is no such compensation. Any slight imperfection at any point on the surface of the lens, whether from defective workmanship or bending of the lens itself, produces much less error in the image than in the case of a reflector. The slightest

* Extract from article in January *North American Review.*

imperfection of workmanship or distortion of the mirror from its own weight, as well as any difference of temperature between the front and back, will utterly ruin the image, while the performance of a lens would be much less affected by the same circumstances. Partly for this reason, reflecting telescopes very rarely give any such definition as refractors.

Then again, the refractor will give a much larger per cent of the incident light than the speculum metal reflector. I speak of speculum metal reflectors because the difficulty of preserving the reflecting silver film on large silvered glass mirrors is so great, and the process of resilvering becomes so formidable, that I believe them to be impracticable.

From what I have said, as well as from other considerations, which it is not necessary to mention here, I have not the slightest doubt that our future advance must be along the line of the refracting telescope.

Until a comparatively recent date wooden tubes were used for telescopes, but these being sluggish as regards equalization of temperature, a star image was often defective and showed wings before all the parts of the telescope had acquired the same temperature. This defect, however, has been completely eliminated by the introduction of the metallic tube, which, with a minimum amount of weight, gives a maximum amount of stiffness and produces uniformity of temperature very rapidly.

But, in order that the object-glass, as its size becomes so great, should also rapidly assume and constantly maintain uniformity of temperature in all parts, I have separated the crown and flint lenses in construction so as to allow a free circulation of air between them. In the Lick telescope this separation amounts to some six inches with holes in the sides of the cell, thus allowing a free circulation of air between the lenses.

Thus we have to-day a refracting telescope that has steadily grown in size with increasing perfection in all its parts, and which has, beyond question, a still greater future before it. What the pledge of the past has been, the future will fulfil. What, then, are the possibilities of accomplishment for these great telescopes of the future?

We may answer that they will do great work anywhere, although much depends on the circumstances in which they are placed. For the finest work they should have good atmospheric conditions, but these may be obtained at various places throughout the world, both at ordinary as well as higher altitudes. When used under such conditions much will be added to our present knowledge of astronomy.

The great and rapid strides which have lately been made in astro-physics, principally in the line of photometry, photography and spectroscopy, added to the vast amount of work which will always remain to be done in the older astronomy of motion, opens a field for the most powerful means of research. These monster telescopes may be characterized as the great light-collectors and space-penetrators of the universe, and their province, the solution of the ultimate problems of science.

Astro-Physics.

A NEW TABLE OF STANDARD WAVE-LENGTHS.[*]

HENRY A. ROWLAND.

During the last ten years I have made many observations of
wave-lengths, and have published a preliminary and a final table
of the wave-lengths of several hundred lines in the solar spec-
trum.

For the purpose of a new table I have worked over all my old
observations, besides many thousand new ones, principally made
on photographs, and have added measurements of metallic lines
so as to make the number of standards nearly one thousand.

Nearly all the new measurements have been made on a new
measuring machine whose screw was specially made by my pro-
cess[†] to correspond with the plates and to measure wave-lengths
direct with only a small correction.

The new measures were made by Mr. L. E. Jewell, who has
now become so expert as to have the probable error of one set-
ting about $\frac{1}{1000}$ division of Angström, or 1 part in 5000000 of
the wave-length. Many of these observations, however, being
made with different measuring instruments, and before such ex-
perience had been obtained, have a greater probable error. This
is especially true of those measurements made with eye observa-
tions on the spectrum direct. The reductions of the reading were
made by myself.

Many gratings of 6 in. diameter and 21½ ft. radius were used;
and the observations were extended over about ten years.

The *standard* wave-length was obtained as follows: Dr. Bell's
value of D_1 was first slightly corrected and became 5896.20.
C. S. Peirce's value of the same line was corrected as the result
of some measurements made on his grating and became 5896.20.
The values of the wave-length then become

Weight	Observer	D.
1	Angström, corrected by Thalen	5895.81
2	Müller & Kempf	5896.25
2	Kurlbaum	5895.90
5	Peirce	5896.20
10	Bell	5896.20
	Mean	5896.156

[*] Communicated by the author.
[†] See *Encyc. Brit.*, Art. *Screw*.

As the relative values are more important for spectroscopic work than the absolute, I take this value without further remark. It was utilized as follows:

1st. By the method of coincidences with the concave grating, the wave-lengths of 14 more lines throughout the visible spectrum were determined from this with great accuracy for primary standards.

2d. The solar standards were measured from one end of the spectrum to the other many times; and a curve of error drawn to correct to these primary standards.

3d. Flat gratings were also used.

4th. Measurements of photographic plates from 10 to 19 inches long were made. These plates had upon them two portions of the solar spectrum of different orders. Thus the blue, violet and ultra-violet spectra were compared with the visible spectrum, giving many checks on the first series of standards.

5th. Measurements were made of photographic plates having the solar spectrum in coincidence with metallic spectra, often of three orders, thus giving the relative wave-lengths of three points in the spectrum.

Often the same line in the ultra-violet had its wave-length determined by two different routes back to two different lines of the visible spectrum. The agreement of these to $\frac{1}{100}$ division of Angström in nearly every case showed the accuracy of the work.

6th. Finally, the important lines had from 10 to 20 measurements on them, connecting them with their neighbors and many points in the spectrum, both visible and invisible; and the mean values bound the whole system together so intimately that no changes could be made in any part without changing the whole.

This unique way of working has resulted in a table of wave-lengths from 2100. to 7700 whose accuracy might be estimated as follows:

Distribute less than $\frac{1}{100}$ division of Angström properly throughout the table as a correction, and it will become perfect within the limits 2400 and 7000.

The above is only a sketch of the methods used. The complete details of the work are ready for publication but I have not yet found any journal or society willing to undertake it.

DESCRIPTION OF THE TABLE.

The first column gives the name of the element whose wavelength has been measured. If a letter stands at the left, it is the

"name" of the line in the solar spectrum. An ? mark after an element means that it is doubtful if the line is really due to the element named. If two elements are given *on the same line* (*e. g.* Mn–Di w. l. 3295.957), it is to be understood that they have apparently coinciding lines at that particular wave-length. If two or more elements are bracketed

$$e. \, g., \quad \begin{matrix} \text{Mn} \\ \text{Ti} \\ \text{Fe} \end{matrix} \Bigg\} \; \text{w. l. 5260.384}$$

it means that the first one has a line coinciding with one side of the corresponding line in the solar spectrum, the second one has a line coinciding with the middle, etc., and the appearance of the solar line itself is given in a later column. An ? standing alone denotes that the element which corresponds to the given wavelength is unknown.

The second column gives the intensity of the line in the arc-spectrum; the third its appearance, and the fourth and fifth do the same for the line in the solar spectrum. R stands for "reversed;" d, double; t, triple; ?, doubtful or difficult. The size of the number indicates to some extent the intensity of the line. For instance the intensity 10 means that the line is apparently 10 times as intense as the intensity 1. Measurements, of intensity by eye-observations, direct or on photographic plates, are of course most uncertain. And so the figures given are estimates which do not apply to comparisons of different portions of the spectrum, but which are intended to give some idea of the relative effects. The intensity of some lines in the arc-spectrum of a given substance, *e. g.*, Ca, is often so much greater than that of the others, that the absence of some lines in the solar spectrum is easily understood. The sixth column gives the character of the standard. M means that the line is a standard in the arc-spectrum; ⊙ means that the line is an ordinary solar standard; ⊙′, a better solar standard; ⊙″, a remarkably good solar standard; and ⊙₁ a rather poor solar standard.

The next two columns give the "weights" to be attached to the values of the wave-lengths as standards in the arc and solar spectra, respectively.

The last two columns give the final values of the wave-lengths measured in Ångström units, *i. e.*, in ten millionths of a millimetre in ordinary air at about 20° C. and 760 mm. pressure.

Notes marked J, are by Mr. Jewell.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Sr	2				M	1		2152.912	
Sr	3				M	1		2165.990	
Si	2				M	2		2208.060	
Si	3				M	2		2210.939	
Si	2				M	2		2211.759	
Si	4				M	2		2216.760	
Si	2				M	2		2218.146	
Al	3				M	2		2263.507	
Al	4				M	2		2269.161	
Sr	10	R			M	1		2275.376	
Ca	20	R			M	3		2275.602	
Fe?					M	2		2298.246	
Ba	20	R			M	1		2304.364	
Ba	20	R			M	1		2335.267	
Fe					M	2		2343.571	
Fe					M	2		2348.385	
Fe					M	2		2364.897	
Al	6				M	3		2367.144	
Al	7				M	3		2373.213	
Fe					M	2		2373.771	
Fe?					M	3		2382.122	
Fe					M	2		2388.710	
Fe?					M	3		2395.715	
Ca	25	R			M	5.		2398.667	
Fe					M	2		2399.328	
Fe					M	2		2404.971	
Fe					M	2		2406.743	
Fe					M	2		2410.604	
Si	8				M	15		2435.247	
Si	3				M	10		2438.864	
Si	3				M	10		2443.460	
Fe?					M	3		2447.785	
Si	3				M	10		2452.219	
Fe?					M	3		2457.680	
Fe					M	3		2462.743	
Fe					M	3		2472.974	
C*	10				M	15		2478.661	
Fe					M	3		2479.871	
Fe					M	3		2483.359	
Fe					M	3		2484.283	
Fe					M	3		2488.238	
Fe					M	3		2489.838	
Fe					M	3		2490.723	
Fe					M	3		2491.244	
Bo	15				M	20		2496.867	
Bo	20				M	20		2497.821	
Fe	.				M	3		2501.223	
Si	10				M	15		2506.994	
Fe					M	3		2510.934	
Si	7				M	10		2514.417	
Si	15				M	7		2516.210	
Fe					M	3		2518.188	

* This line seems to be the only single line of carbon not belonging to a band in the arc spectrum. It was determined to belong to carbon by the spark spectrum (R).

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Si	8				M	10		2519.297	
Fe					M	3		2522.948	
Si	9				M	10		2524.206	
Fe					M	3		2527.530	
Si	10				M	5		2528.599	
Fe					M	3		2535.699	
Hg*	50	R			M	2		2536.648	
Fe					M	3		2541.058	
Fe					M	3		2546.068	
Fe					M	2		2549.704	
Al	10				M	5		2568.085	
Al	10				M	5		2575.198	
Mn					M	2		2576.195	
Fe?					M	2		2584.629	
Fe					M	2		2585.963	
Mn					M	2		2593.810	
Fe					M	2		2598.460	
Fe		R			M	3		2599.494	
Fe					M	2		2611.965	
Fe					M	3		2631.125	
Si	5				M	7		2631.392	
Fe					M	3		2679.148	
Fe	·				M	2		2706.684	
Fe					M	3		2719.119	
Fe					M	3		2720.989	
Ca	5				M	1		2721.762	
Fe					M	3		2723.668	
Fe?					M	3		2733.673	
Fe?					M	3		2737.405	
Fe					M	3		2742.485	
Fe					M	3		2750.237	
Fe					M	2		2755.837	
Fe					M	3		2756.427	
Fe					M	2		2761.876	
Fe					M	2		2762.110	
Fe					M	2		2767.630	
Fe					M	2		2772.206	
Mg†	5	R			M	5		2776.798	
Fe					M	2		2778.340	
Mg†	5	R			M	3		2778.381	
Mg†	8	R			M	5		2779.935	
Mg†	5	R			M	5		2781.521	
Fe					M	1		2781.945	
Mg†	5	R			M	5		2783.077	
Fe					M	3		2788.201	
Mn					M	3		2794.911	
Mg	20	R			M	12		2795.632	
Mn					M	3		2798.369	
Mn					M	3		2801.183	
Mg	20	R			M	10		2802.805	
Fe	5				M	3		2813.388	
Fe	3				M	1		2823.389	

* This line shows as a sharp reversal, with no shading, in the spectra of all substances tried, that contained any trace of continuous spectrum in this region (J).
† A remarkable symmetrical group of five lines in the spectrum of magnesium.

Elements.	In Arc. Intensity.	In Arc. Appearance.	In Sun. Intensity.	In Sun. Appearance.	Kind of Standard.	Weight. In Arc.	Weight. In Sun.	Wave-length in Arc.	Wave-length in Sun.
Fe	5				M	1		2825.667	
Fe	4				M	7		2832.545	
Fe	3				M	1		2838.226	
Fe	3				M	1		2843.744	
Fe	5				M	7		2844.085	
Fe	6				M	5		2851.904	
Mg	100	R			M	15		2852.239	
Si	15				M	12		2881.695	
Fe	7	R			M	3		2912.275	
Fe	8	R			M	3		2929.127	
Fe	10	R			M	4		2937.020	
Fe	8	R			M	4		2947.993	
Fe	7	R			M	4		2954.058	
Fe	5				M	3		2957.485	
Fe	5				M	3		2965.381	
Fe					M	1		2966.985	
Fe	8	R			M	12		2967.016	
Fe	4	R			M	7		2970.223	
Fe	6	R			M	7		2973.254	
Fe	12	R			M	15		2973.358	
Fe	2				M	6		2981.570	
Fe	10	R			M	15		2983.689	
Fe					M	1		2987.410	
Si	4				M	5		2987.766	
Fe	8	R			M	18		2994.547	
Ca	7	R			M	3		2995.074	
Ca	10	R			M	3		2997.430	
Fe	4	R			M	5		2999.632	
Ca	6	R			M	3		2999.767	
Ca	8	R			M	3		3000.976	
Fe	8	R			M	15		3001.070	
?			3		⊙	1			3005.160
?			4		⊙	1			3005.404
Ca	15	R			M	3		3006.978	
Fe	2				M	1		3007.260	
Fe	1				M	3		3007.408	
Fe	6	R			M	15		3008.255	
Ca	7	R			M	3		3009.327	
Fe	4	R			M	3		3009.696	
?			4		⊙'	5			3012.557
?			6	d?	⊙'	4			3014.274
Fe			3		M	1		3016.296	
Fe	5				M	1		3017.747	
Fe	5				M	1		3019.109	
Fe					'M	1		3019.752	
Fe	10	R			M	15		3020.611	
Fe	25	R			M	18		3020.759	
Fe	15	R			M	18		3021.191	
Fe	7	R	7		M	7		3024.154	
?			5		⊙'		7		3024.475
?			4		⊙'		7		3025.394
Fe	10	R	10		M	7		3025.958	
Fe					M	1		3027.245	
?			5		⊙	7			3035.850
Fe	15	R	15		M	10	2	3037.505	3037.492

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Ca	15	R	4		M ⊙₁	3	2	3044.114	3044.119
Mn	10	R	3		⊙′	5			3044.683
?					⊙′	1			3046.778
Fe	20	R	20		M	13		3047.720	
?			3 }	d	⊙″		5		3050.212
			3 }						
Fe			3		⊙′		5		3053.173
?			3 }	d	⊙′		1		3053.527
			3 }						
?			5	d?	⊙″		5		3055.821
Fe	10	R	10		M	8		3057.557	
Fe	10	R	10		M	15		3059.200	
?			3		⊙′		1		3061.098
Co	8	R	3		M ⊙″	1	5	3061.932	3061.930
Fe	10	R	10		M	10		3067.363	
Ti	6		8		M	3		3075.339	
Fe	10	R	10		M	4		3075.849	
Fe			2		M	1		3077.216	
?			4		⊙		6		3077.303
Fe?			4		⊙″		6		3078.148
Ti			6		M	3		3078.759	
Mn	7		2		⊙″		1		3079.724
?			5		⊙″		1		3080.863
Al	20	R	7		M	17		3082.272	
Fe	6	R	7		M	5		3083.849	
?			4		⊙″		1		3086.891
Ti	8	R	8		M	1		3088.137	
Al	20	R	10		M	15		3092.824	
Al	4		2		M	8		3092.962	
?			2		⊙′		9		3094.739
Fe	1		3		⊙′		9		3095.003
Fe	4		7		M	3		3100.064	
Fe(Mn)	4-?		4		M	3		3100.415	
Fe	6		6		M	3		3100.779	
Ni	20	R	8		M	3		3101.673	
Ni	10	R	6		M	3		3101.994	
?			2		⊙		1		3106.677
Cr?			3		⊙′		1		3109.434
Fe			2		⊙″		3		3115.160
Va*	7		5		⊙″		9		3121.275
Zr	3		1		⊙′		5		3129.832
Ni	10	R	8		M	1		3134.223	
Co	4		2		⊙′		3		3137.441
Fe			3		⊙′		5		3140.869
Fe			2		⊙′		3		3153.870
Ca			8		M	1	1	3158.994	3158.988
Mn			1		⊙′		5		3167.290
Fe?			5		⊙″		1		3172.175
La?	1		1		⊙′		5		3176.104
Cr?	4	N	4		⊙′		5		3188.164
Ni†	3		3		M	1	1	3195.729	3195.702
Ti	10	R	4		M ⊙″	1	5	3200.040	3200.032

* There is a very faint line on the violet side in the solar spectrum.
† There is a line towards the red, also.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	5		5		M	1		3214.152	
Ti	4		3		☉″		6		3218.390
Fe			6⎰		☉′		1		3219.697
Fe			6⎱		☉′		1		3219.909
Fe?⎰	6		5⎰	d	M☉	3	1	3222.197	3222.203
? ⎱	?⎰		7⎱						
Ti	6		4		☉″		3		3224.368
Fe	8		8		M	3	1	3225.907	3225.923
Ti⎰	5⎰		5		☉″		1		3231.421
? ⎱	?⎱								
Ti	6		4		☉		12		3232.404
Ti	10	R	8		M	1	1	3236.696	3236.697
?⎰			6		☉″		12		3246.124
Fe⎱									
Cu	40	R	9		M☉₁	15	5	3247.671	3247.680
Mn⎤	4								
Ti ⎬	3		4		☉′		10		3260.384
Fe ⎦	1								
Va	10		4		☉″		10		3267.839
Cu	30	R	6		M☉″	15	5	3274.090	3274.092
Ti	6		5		☉″		9		3287.791
Fe ⎱	5		5	d?	☉″		10		3292.174
Co–T⎰	4 7								
Mn–Di	3 2		4		☉″		9		3295.957
Na	15	R	6		M☉″	1	6	3302.504	3302.501
Na*	10	R	5		M☉₁	1	6	3303.119	3303.107
? ⎰			3⎰	d	☉′		10		3303.648
Fe⎱			3⎱						
Fe†	10		7		M☉₁	1	5	3306.119	3306.117
Fe‡	10		7		M☉₁	1	5	3306.481	3306.471
Mn ⎱	2		1⎰	d	☉″		10		3308.928
Co–Ti⎰	3 6		4⎱						
Ti	5		5		☉″		10		3318.163
Fe	2		2		☉′		8		3331.741
Cr⎰	3		3⎰	d	☉′		9		3348.011
Fe⎱	3		3⎱						
Fe	2		2		☉′		9		3351.877
Zr	4		1		☉″		8		3356.222
Ti ⎰§	5		3	d	☉″		9		3377.667
Ti ⎱	5		3						
Fe	2		2		☉″	1	12	3389.913	3389.887
Co⎰	10	R	3⎰	d	☉′	1	12	3405.255	3405.272
Ti ⎱	1		3⎱						
Fe	2		1		☉′	1	18	3406.602	3406.581
Fe	5		4		.☉′	1	18	3406.965	3406.955
?			2		☉″		15		3425.721
Fe‖	6		5		M	2	1	3427.279	3427.282
Fe	15	R	15		M☉₁	7	4	3440.756	3440.759

* Red component of a double which has a Zn line between. There is another Zn line at about 3302.7 in the solar spectrum.
† Second line from red side of a group of five lines.
‡ Second line from violet side of a group of four lines.
§ A very wide nebulous line of Ba comes here.
‖ Red component of a double (the other line being also Fe) having another fainter line at the red edge.

| Elements. | In Arc. | | In Sun. | | Kind of Standard. | Weight. | | Wave-length in Arc. | Wave-length in Sun. |
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	10		10		M☉₁	6	4	3441.135	3441.135
Fe	8	R	8		M☉₁	6	4	3444.024	3444.032
Co	6	R	4		☉″		10		3455.384
Sr?	8		3		☉″		8		3464.609
Co}*	10	R	4}	d	M	7	3	3466.010	3465.991
Fe}	10	R	6}						
Fe†	10	R	10		M	7	3	3475.602	3475.594
Fe‡	7	R	8		M	5	2	3476.848	3476.831
Co}	2								
Fe}	3		4		☉″		10		3478.001
Ni}	2								
Ni	4	R	5		☉′		9		3486.036
Fe§	10	R	10		M	7	3	3490.724	3490.721
Co}	4	R	4		☉″		8		3491.464
?}	?								
Fe‖	5		5		M	1	1	3497.266	3497.264
Fe‖¶	6	R	7}	d	M	5	4	3497.991	3497.991
?}	?		3}						
Fe	2		3		☉″		4		3500.721
Ni	7	R	7		☉″		4		3500.993
Ti**	5		4		☉′		8		3510.987
Fe††	7	R	6		M	2	3	3513.981	3513.947
Co	6	R	5		☉″		10		3518.487
Th	40	R			M	1		3519.342	
Fe	5	R	7		M	6	5	3521.409	3521.404
Th	20	R			M	1		3529.547	
Fe	3		5		☉″		10		3540.266
?			4		☉″		6		3545.333
Yt	6		2		M☉″	1	1	3549.147	3549.145
Fe	2		3		☉″		7		3550.006
Fe	9	R	8		M☉	3	4	3558.674	3558.670
Ti}	2								
Fe}	1		4	d?	☉″		12		3564.680
Fe	10	R	12		M	6	4	3565.530	3565.528
Fe ‡‡	20	R	20		M	8	4	3570.253	3570.225
Fe	10		10		M	1	1	3570.412	3570.402
Fe	30	R	40		M☉₁	9	6	3581.344	3581.344
Fe?	2		4		☉″		12		3583.483
Yt	6		2		M	1	1	3584.662	3584.662
C§§	2		1		M	8		3585.992	
C			2		M	2		3586.041	
C‖‖			3		M	7		3590.523	
Fe	5		4		☉″		12		3597.192

     * The metal measured was Fe.
     † Strongest line of group of six lines.
     ‡ Also the strongest line in a group of six lines.
     § There is a Co line near this towards the red.
     ‖ Red component of a double.
     ¶ Violet component of a double. Other component was not measured.
     ** A strong compound bismuth line comes here also.
     †† Violet component of a double.
     ‡‡ Red component of a double with another Fe line towards the red.
     §§ First line in the second head of the carbon band.
     ‖‖ First line in the first head of carbon band.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Yt (Fe)	10-?		4		M☉″	1	1	3600.884	3600.880
Yt	6		2		M☉	1	1	3602.065	3602.061
Cr*	10	R	4		M☉₁	1	2	3605.497	3605.483
Fe*	5		7	d	M☉₁	2	2	3605.621	3605.635
Fe†	4		6		M	2	2	3606.836	3606.831
Fe	15	R	15		M☉	11	10	3609.015	3609.015
Yt	7		3		M☉	1	1	3611.196	3611.193
Fe	4		4		☉′	1	15	3612.237	3612.217
Ca‡ } Fe }	4		2 } 3 }	d	M☉₁	1	1	3617.939	3617.920
Fe	20	R	20		M☉₁	11	10	3618.922	3618.924
Yt	3		1		M	1	1	3621.096	3621.122
Fe	4		4		M☉	2	2	3621.616	3621.606
Fe	4		4		M☉₁	2	3	3622.161	3622.147
Fe	4		4		M☉″	1	14	3623.338	3623.332
Fe§	2		3		☉″		10		3623.603
Yt	3		2		M☉	1	1	3628.853	3628.853
Fe	20	R	20		M☉₁	11	10	3631.616	3631.619
Yt‖	5		3	d	M	1	1	3633.277	3633.259
Ti	10	R	3		M☉′	3	1	3635.615	3635.616
Fe	5		5		M☉₁	1	1	3638.454	3638.435
Pb¶	50	R	1		M	4		3639.728	
Cr‡ } Fe }	2 5		5		M☉″	1	14	3640.545	3640.536
Fe	10	R	10		M☉	10	11	3647.995	3647.995
Co	5	R	3		☉″		5		3652.692
Ti	10	R	4		M☉′	2	7	3653.639	3653.639
Mn } Fe }	2 2		2		.☉″		7		3658.688
Fe	5		3		☉″		13		3667.397
Fe	8	R	8		M☉	8	7	3680.064	3680.064
Co } Fe } ** Va }	9 3 4		6		☉″	1	13	3683.209	3683.202
Pb	60	R	1		M	5		3683.622	
Fe	5		6		☉″	1	14	3684.268	3684.259
Fe	10	R	8		M☉	8	6	3687.609	3687.607
Yt			3		M☉	1	1	3694.351	3694.349
Fe	5		5		☉″	1	11	3695.208	3695.194
Fe††	7	R	8		M☉	7	5	3705.715	3705.711
Fe	5		5		☉″	1	11	3707.201	3707.186
Fe	10	R	10		M☉₁	6	4	3709.395	3709.397
Yt	10		3		M☉	1	1	3710.442	3710.438

* In the solar spectrum these belong to a group of several lines. Of the three most prominent, the middle line is Cr. with possibly a weak line on its red edge; and the red one is a close double, the violet component of the double being Fe (J).

† The solar line is a group of four lines. The third from the violet side is the brightest and is Fe.

‡ Metal measured was Fe.

§ There is a faint line on the red side.

‖ Red component of double.

¶ In the solar spectrum this is the red component of a double, the other being cobalt.

** The metallic line measured was Fe.

†† Violet component of a double.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	4		7		☉″	1	12	3716.601	3716.585
Fe	40	R	50		M☉	11	10	3720.082	3720.086
Ni }*	4		10	d	M☉	7	5	3722.712	3722.691
Fe–Ti}	8 5								
Fe	6	R	7		M	5	3	3727.768	3727.763
Fe	5		5		☉″	1	15	3732.549	3732.542
Fe	6	R	7		M☉	5	3	3733.467	3733.467
Fe	40	R	50		M☉	8	7	3735.012	3735.014
Ni }	6		3}		☉₁		2		3736.969
Mn}	2		5}	d					
Ca	4	R	5}		M☉₁	2	3	3737.081	3737.075
Fe	25	R	30		M☉	7	8	3737.280	3737.282
Ti}	3		2}						
Fe}*	5		6}	t	M☉	4	2	3743.506	3743.502
Cr}	3		2}						
Fe†	10	R	10		M	8	6	3745.708	3745.701
Fe	7	R	7		M	6	5	3746.048	3746.054
Fe}*	3								
?}	?		7	d	☉′	1	9	3747.082	3747.095
Fe	10	R	10		M☉	7	8	3748.410	3748.409
Fe	20	R	20		M☉	7	8	3749.633	3749.633
?}			2}	d	☉		12		3754.664
?}			1}						
Fe	2		2		☉′		12		3756.211
Fe	15	R	15		M☉	8	7	3758.380	3758.379
Fe	9	R	10		M	9	8	3763.939	3763.942
Fe	7	R	8		M☉	9	8	3767.342	3767.344
Fe	3		4	d?	☉		12		3770.130
Yt?	6		3		M☉	1	1	3774.478	3774.480
Th	40	R			M	1		3775.869	
?			4		☉′		15		3780.846
Fe	2		3		☉′		15		3781.330
Ni	10	R	6		☉		15		3783.674
Fe	7	R	8		M☉	3	3	3788.029	3788.032
Fe–Cr	1 1		3		☉		15		3794.014
Fe‡	8		8		M	3	4	3795.148	3795.150
Fe	7		7		☉		2		3798.662
Fe	8		8		☉		2		3799.698
Fe	2		3		☉″		15		3804.153
Fe–Di	4 ?		6		☉″		15		3805.487
Fe	20	R	20		M☉	4	3	3815.984	3815.985
Fe	30	R	30		M☉	4	4	3820.566	3820.567
Fe	5		6		☉′		10		3821.318
Mn(Cr)	5 1	R	5		☉′		10		3823.651
Fe	20	R	20		M☉	4	4	3826.024	3826.024
Fe	8	R	8		M	1	1	3827.973	3827.973
Mg	20	R	8		M		2		3829.505
Mg	30	R	10		M		2		3832.446
?–c			4		☉		8		3836.226
C§			5	d	M☉₁	1	1	3836.638	3836.652
Mg	40	R	20		M		2		3838.430

* The metallic line measured was Fe.
† Violet portion of broad solar double is composed of three lines, the red line is Fe and the middle one Co (J)
‡ There is a Va line towards the violet.
§ Central line of symmetrical group in carbon band.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	7	R	7		M	1	2	3840.589	3840.584
Fe	4		5		⊙		8		3843.406
Fe	6		7		M	1	2		3856.517
Fe	10	R	10		M⊙₁	2	3	3860.050	3860.048
C*			3		⊙'		8		3864.441
C†			4		M	4	4	3871.527	3871.528
? } Va }			3		⊙		15		3875.224
C‡			7		M⊙₁	5	3	3883.479	3883.472
C§					M⊙₁		8	3883.523	3883.548
Cr			1		⊙		12		3883.773
Fe	15	R	9		M⊙₁	7	6	3886.421	3886.427
Fe	3		4		⊙'		12		3897.599
Si	10	R	10		M	4	4	3905.670	3905.666
Fe	3		3		⊙'	1	12	3916.886	3916.875
Ti	6		4		⊙'		15		3924.669
Fe } Va }	1 / 2		4		⊙'		15		3925.345
Fe	3		4		⊙		13		3925.792
Fe‖ } ? }	5 / ?		4} 4}	d	⊙'		12		3926.123
Fe	10	R	8		M	1	3	3928.060	3928.071
K Ca¶	75	R	300		M	6	5	3933.809	3933.809
Fe	3		4		⊙'		8		3937.474
Fe-Co	4 4		5		⊙	1	15	3941.034	3941.021
? }** Fe }	? / 5		2} 4}	d	⊙		15		3942.559
Al	20	R	10		M⊙₁	7	7	3944.165	3944.159
Ca††	4		2		M	1	2	3949.070	3949.034
Fe	4		4		⊙''		15		3950.101
Yt	10		2		⊙		13		3950.497
Fe	2		2		⊙'		13		3954.001
Fe-Ca	5 6		6		⊙'	1	2	3957.228	3957.180
Fe	3		3		⊙''		11		3960.429
Al	30	R	15		M⊙₁	7	8	3961.680	3961.676
H Ca¶	70	R	200		M	7	5	3968.617	3968.620
H ‡‡					M			3970.05	
Fe§§	5		4		⊙'		11		3971.478
Ca‖‖	5		3		d — M	1	2	3973.881	3973.835
Fe	5		4		⊙''		15		3977.891

* One of the lines in the carbon band.
† Second head of carbon band.
‡ First line of first head of carbon band.
§ Edge of first head of carbon band.
‖ .087 apart.
¶ The solar line is doubly reversed and spread out into broad shading for 6.000 or 7.000 on either side. In each case the second reversal is slightly eccentric with respect to the other or displaced slightly toward the red (J).
** Components .085 apart.
†† Red component of a triple.
‡‡ Value determined by Dr. Ames.
§§ Red component of a double.
‖‖ Red component of double, the violet component being Fe. There is also a Ni line close to violet side.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe–Ti	6?		4		☉		14		3981.914
Cr }*	5		6	d	☉		9		3984.078
Fe }	3								
? }‡	3?		7}	d	☉		9		3986.903
Mn }	4		1}						
? }‡	?								
Mn }	4		6	t	☉		4		3987.216
Co }	2								
Ce–Fe–Ti	4 1 2		3		☉		9		4003.916
Fe–?§	10		10		☉		3		4005.305
Fe			3		☉″		7		4016.578
Fe}	2		4		☉″		10		4029.796
Zr }	2								
Mn‖	30	R	7		M	3	4	4030.919	4030.914
Mn‖	25	R	6		M	3	4	4033.230	4033.225
Mn¶	20	R	5		M	3	4	4034.642	4034.641
Mn¶	7		3		M			4035.88	4035.88
K	50	R	1		M	2	2	4044.301	4044.293
Fe	20	R	20		M☉₁	7	7	4045.975	4045.975
K	40	R	1?		M	2		4047.373	
Zr }	1								
Mn }**	8		6	d	☉		13		4048.893
Cr }	2								
Mn	8		5		☉″		13		4055.701
Fe	5		5		☉″		8		4062.602
Fe	15	R	15		M☉₁	7	7	4063.755	4063.756
Fe	10		10		M☉₁	7	9	4071.903	4071.904
Fe	4		4		☉″		14		4073.920
Sr	50	R	8		M☉₁	5	6	4077.876	4077.883
Fe }	2		2}	d	☉		7		4083.767
Mn}	5		4}						
Fe	2		2		☉		7		4083.928
Fe	2		2		☉″		8		4088.716
Si }	3		6		☉″		10		4103.101
Mn}	1								
Fe	5		5	d?	☉″		12		4107.646
Fe	3		4		☉″		14		4114.600
Cr }††	1		1						
Co}	10	R	3		☉	1	12	4121.476	4121.481
Fe–Cr	3 1		3		☉′		13		4121.968
Fe	4		3		☉″		17		4157.948
C					M			4158.2	
Fe	4		3		☉″		20		4185.063
C‡‡			1		M☉	5	6	4197.256	4197.251

* Components about .060 apart.

† Hazy line shaded to red, shading due to a Mn line on red side.

‡ Triple line. Central line brightest.

§ Seven or eight lines. The brightest and most of the others are due to Fe.

‖ Violet component of double being itself double or reversed in Sun. The other component is weak.

¶ Red component of double being itself double or reversed in Sun. The other component is weak.

** An unequal double, violet component much the weaker.

†† Cobalt line measured.

‡‡ First line of second head of carbon band.

Elements.	In Arc. Intensity.	In Arc. Appearance.	In Sun. Intensity.	In Sun. Appearance.	Kind of Standard.	Weight. In Arc.	Weight. In Sun.	Wave-length in Arc.	Wave-length in Sun.
Zr }	2		5		⊙ʺ	2	22	4199.257	4199.263
Fe }	5								
Fe	8		5		⊙ʹ	2	4	4202.187	4202.188
Fe }	2	2	}	d	⊙		2		4215.616
							18		4215.667
Sr }	40	R	4 }		M⊙	6	3	4215.688	4215.687
C*			1		M⊙	4	2	4216.133	4216.137
Fe	2		4		⊙ʺ	1	22	4222.396	4222.381
g Ca	50	R	10		M⊙	9	10	4226.898	4226.892
Fe	4		5		⊙ʹ	1	1	4250.300	4250.290
Fe	5		7		⊙ʹ	4	3	4250.949	4250.956
Cr	20	R	7		M⊙ʺ	2	15	4254.494	4254.502
Fe	6	R	7		⊙	4	3	4260.647	4260.638
? }	?		1 }	d	⊙		12		4267.958
Fe }	1		2 }						
Fe	10	R	8		M⊙	8	9	4271.920	4271.924
Cr	15	R	5		M⊙	1	2	4274.954	4274.958
Ca	5	R	3		M⊙	2	4	4283.175	4283.170
Ca	4	R	3		M⊙	3	5	4289.527	4289.523
Cr	10	R	4		M⊙	2	2	4289.884	4289.881
?			4	d	⊙ʹ		14		4293.249
Ca	3	R	2		M⊙	3	5	4299.153	4299.152
Ca	6	R	4		M	5	7	4302.690	4302.689
Sr	8		2		M	1		4305.636	
Ti	10	R	4		M⊙	4	4	4306.071	4306.071
Ca }	4	R	2 }		⊙	3	3	4307.906	4307.904
G {				d	⊙		3		4308.034
Fe }	7	R	5 }		⊙	8	10	4308.072	4308.071
Ca	4	R	3		M⊙ʺ	3	16	4318.816	4318.818
f Fe	10	R	8		M⊙ʹ	8	15	4325.932	4325.940
Cr }	2		1 }	d?	⊙		11		4343.387
Fe }	2		2 }						
Fe	4		3		⊙ʺ	1	17	4352.908	4352.903
Ni }	3		1 }						
Cr }	4		3 }	t	⊙		10		4359.778
Zr }	5		1 }						
Fe	4		5		⊙ʺ	1	14	4369.948	4369.943
Fe	5		5		⊙ʺ	1	17	4376.108	4376.103
d Fe	15	R	10		M⊙ʹ	10	11	4383.721	4383.721
Fe }†	2		3		⊙		14		4391.149
Ti }	1		1						
Fe	10	R	8		M⊙	10	11	4404.928	4404.927
Va }	9	R	2 }	d	⊙		19		4407.850
Fe }	3		3 }						
Cd	6		6		M	3		4413.181	
Fe	4	R	4		M⊙	9	7	4415.298	4415.299
Ca	5	R	4		M⊙ʺ	5	7	4425.616	4425.609
Ca	5	R	4		M⊙	5	5	4435.133	4435.132
Ca	4	R	3		M⊙ʺ	5	6	4435.856	4435.852
Fe‡	8		5		⊙ʺ	2	18	4447.912	4447.899
Ca§	6	R	6		M⊙₁	6	6	4454.949	4454.950

* First line in first head of carbon band.
† Unequal double, components being about .050 apart.
‡ There is a faint side line to red.
§ There is a faint line close to violet.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Ca*	3	R	2		M	5	3	4456.055	4456.047
Ca	1		1		M⊙₁	2	2	4456.791	4456.793
Fe			5		⊙″	1	18	4494.756	4494.735
Cr } Zr }	5 2		4 } 1 }		⊙₁		14		4497.041
Mn } ? }			2 } 1 }	d	⊙″ ⊙′		8 7		4499.070 4499.315
Ti	6		5		⊙′		18		4501.444
C								4502.6	
Ti?			4		⊙″		17		4508.456
In					M	4		4511.474	
In					M	3		4513.883	
Ba	70	R	7		M⊙″	6	8	4554.212	4554.213
Ti	4		6		⊙″		13		4563.939
Mg	3		5		⊙″	1	14	4571.281	4571.277
Ti	5		6		⊙″		14		4572.157
Ca-Ti	3 1	N	4		⊙″	1	14	4578.807	4578.731
Cr?			4		⊙″		14		4588.384
Ti?			4		⊙″		15		4590.129
Fe			4		⊙″		20		4602.183
Li†	50	R			M	1		4602.25	
C‡								4606.6	
Sr	50	R	2		M⊙′	5	4	4607.506	4607.509
? } § Fe }	? 4	R	2 } 6 }	d	⊙₁		11		4611.453
Ti } Co }	4 5		5		⊙′		13		4629.515
Fe	3		4		⊙′		14		4637.683
Fe	3		4		⊙′		14		4638.194
Fe	2		4		⊙″		17		4643.645
Ni	6	R	3		M⊙	1	1	4648.833	4648.835
? } Fe }	? 3		2 } 5 }	d	⊙′		11		4668.303
Cd			4?		M	3	3	4678.339	4678.353
Fe	3		6		⊙′		12		4679.028
Zn			2		M	1		4680.319	
Fe	2		3		·⊙″		13		4683.743
Ni	4		4		⊙″		12		4686.395
?			4		⊙′		14		4690.324
Ti } ‖ Fe }	3 3		2 } 4 }	d	⊙₁		11		4691.581
Mg ¶	5		9		⊙″	1	11	4703.249	4703.180
Ni	3		3		⊙″		13		4703.986
Ni**	9	R	6	d?	M⊙	1	1	4714.598	4714.599
Zn	4		4		M⊙″	2	2	4722.339	4722.349
Fe } Mn }	2 7		4 } 3 }	d	⊙		11		4727.628

* Red component of a double. Other line is Mn.
† First line in first head of blue carbon band.
‡ Strong line with fine line very close to violet and another farther to violet.
§ Besides the double line measured there is another fine line near the red side.
‖ The Mg. line is of the nature of a band, shaded toward the red. It coincides with the solar line when there is very little material in the arc (R).
¶ Solar line is shaded towards the violet, probably owing to a close side line.
** Much the same in character as the red lithium line (J)

Elements.	In Arc. Intensity.	In Arc. Appearance.	In Sun. Intensity.	In Sun. Appearance.	Kind of Standard.	Weight. In Arc.	Weight. In Sun.	Wave-length in Arc.	Wave-length in Sun.
Mn	15	R	6		⊙ "		11		4754.226
Mn	10	R	6		M ⊙ "	1	1	4783.607	4783.601
Cd			?		M	3		4800.097	
?⎱ Ti⎰	? 1		1⎰ 4⎰	d	⊙₁		3		4805.253
Zn			3		M ⊙ "	1	1	4810.725	4810.723
Mn	10		6		M ⊙ "	1	12	4823.715	4823.697
Fe?			4		⊙ "		11		4824.325
Fe	4		5		⊙ "		14		4859.934
F H			15		⊙ '		5		4861.496
Fe	7		7		⊙ "		11		4890.945
Ti*	4		2⎱	d	⊙ '		11		4900.098
Yt*			2⎰		⊙ '		11		4900.306
Cr⎱ Fe⎰	2 5		6	d?	⊙ "		14		4903.488
Pb					M	1		4905.634	
Fe	6		7		⊙ "		4		4919.183
Fe†	9		9		M ⊙ "	1	7	4920.676	4920.682
Fe	2		4		⊙ "		13		4924.109
Fe	3		2		⊙ "		12		4924.955
Ba‡	60		7	d?	M ⊙	1	10	4934.237	4934.247
Fe			6		M ⊙₁		3		4957.482
Fe			8		M ⊙₁		3		4957.786
Neb**								4959.02	
Ti⎱ Fe⎰	1 3		3		⊙ "		10		4973.274
?⎱§ Fe⎰	3		1⎱ 3⎰	d?	⊙ "		8		4978.782
Ni⎱§ ?⎰	5 ?		3⎱ 1⎰	d	⊙		5		4980.362
Ti	10		4		⊙	1	10	4981.893	4981.915
Fe	3		4		⊙ "		7		4994.316
Ti–La‖	10 10	R N	4		M ⊙		8	4999.668	4999.693
Pb					M	5		5005.634	
Fe	3		4		⊙ '		10		5005.904
Fe¶			6		⊙ "		8		5006.303
Ti⎱ Fe⎰	10 3	R	4⎱ 3⎰	d	⊙ ¨		10		5007.431
Neb**								5007.05	
Mg b'd††					M	3	10	5007.473	
(Ni)Ti⎱	?10		3⎱ 4⎰	d	M ⊙ '		10	5014.412	5014.422
Ti ⎰	5				⊙ '		8		5020.210
Ti	7		3		⊙ '		8		
Ti⎱ Ni⎰	6 3		3⎱ 2⎰	d	⊙ '		8		5036.113
Ca	3	N	2		M	2	1	5041.867	5041.795

    * A Ba line comes between these and does not coincide with either.
    † Shaded, and has a faint line to red.
    ‡ A very difficult double with a fine line towards the violet (J).
    § There is a faint line to red.
    ‖ Ti line was measured.
    ¶ There is a faint side line to violet.
    ** Values determined by J. E. Keeler from his measurements at the Lick Observatory using the values of the Pb., Fe. and Mg. lines given in this table.
    †† Commencement of the head of Mg band.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	5		5		⊙″		12		5050.008
Fe	2		2		⊙′		15		5060.252
Ti	10		3		⊙′		12		5064.833
Fe	4		4		⊙″		14		5068.946
Fe	4		3?		⊙″		9		5083.525
Cd			?		M	1		5086.001	
Fe	3		2		⊙″		9		5090.959
Fe*	3		2		⊙₁		7		5097.176
Fe(Cu)	3?		3		⊙″		12		5105.719
Fe	3		2		⊙″		11		5109.825
?⎰ Fe⎱	? / 4		2⎱ 3⎰	d	⊙′		11		5110.570
Ni	5		2		⊙″		9		5115.558
Ni⎰ Fe⎱	2 / 3		1⎰ 3⎱	d	⊙₁		9		5121.797
Co	3		2		⊙″		9		5126.369
Fe	4		4		⊙″		9		5127.530
Fe⎰ ?⎱	1 / ?		6	d	⊙″		12		5133.871
Fe⎰	4		6⎰	d	⊙		4		5139.437
					⊙		4		5139.539
Fe⎱†	5		6⎰		⊙		4		5139.645
Fe	2		3		⊙″		5		5141.916
Ni⎰	5		2⎰		⊙₁		1		5142.967
				d	⊙₁		5		5143.042
Fe⎱	3		4⎰		⊙₁		2		5143.106
Ni⎰ ?⎱	5 / ?		3		⊙″		10		5146.664
Fe ⎰ Mn⎱‡	4 / 2		3⎰ 1⎰	d	⊙		9		5151.026
Ti?Co?			2		⊙″		10		5154.237
Ni	6		2		⊙″		10		5155.937
Fe?			2		⊙″		11		5159.240
Fe	4		4		⊙″		13		5162.448
C§			1		M	2	1	5165.241	5165.190
Fe	2		2		⊙″		10		5165.588
Mg⎰ b₄⎱‖	20	R	8⎰	d	M⊙₁	2	3	5167.488	5167.501
					⊙		7		5167.572
Fe ⎰	6		6⎰		M⊙₁	2	3	5167.664	5167.686
Fe⎰ b₃⎱¶	3		4⎰	d	⊙″		3		5169.066
					⊙″		5		5169.161
Fe⎱	3		4⎰		⊙″		3		5169.218
Fe	5		5		⊙″		11		5171.783
b₂ Mg	35	R	10		M⊙″	2	9	5172.866	5172.871

* The fine line near to violet belongs to Ni?.

† There is a Cr. line near to red.

‡ The Mn line is a faint side line toward the red from the Fe line.

§ Measurements in the arc spectrum were on the first line of the first head of the green carbon band; measurements in the solar spectrum were probably on the brightest of a group of faint lines near the head of carbon band (J). Much of the band can be seen on my map of the solar spectrum extending to the left (R).

‖ Components about 0.180 apart on photographic plates (J).

¶ Components about 0.138 apart as measured by Rowland in solar spectrum and 0.050 apart as measured on photographic plates (J).

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Ti	10	R	3		⊙″		11		5173.912
b₁ Mg	40	R	20		M⊙″	2	11	5183.791	5183.792
Ti ⎱	2		4 ⎱		⊙″		3		5188.863
⎰ *			⎰	d	⊙″		7		5188.948
Ca ⎰	6		4 ⎰		M⊙″	1	3	5189.019	5189.020
Ti	8		3		M⊙″	2	8	5193.134	5193.139
Fe	3		4		⊙″		10		5198.885
? ⎱	?		2 ⎱	d	⊙″		11		5202.483
Fe ⎰	4		3 ⎰						
Cr ⎱	8	R	4 ⎱	d	⊙″		10		5204.708
Fe ⎰	3		3 ⎰						
Ti	10	R	3		M⊙″	2	12	5210.549	5210.556
Fe	3		4		⊙″		10		5215.352
Fe	3		4		⊙″		10		5217.559
Fe	2		2		☾″		10		5225.690
Fe	4		4		⊙″		8		5230.014
Fe	7		8		⊙″		9		5233.124
Fe	3		3		⊙″		10		5242.662
Fe	2		2		⊙″		11		5250.391
Fe	3		3		⊙″		11		5250.825
Fe	2		· 3		⊙″		12		5253.649
Ca	2		1		M⊙₁	1	5	5260.556	5260.557
Ca ⎱	6								
Cr ⎰	2		3		⊙	1	12		5261.880
? ⎱			1 ⎱	d	M⊙₁		1		5262.341
Ca ⎰	6		2 ⎰		⊙	2	5	5262.408	5262.391
Cr ⎱	4	R	3 ⎱		⊙		3		5264.327
⎰ †			6 ⎰		⊙″		2		5264.371
Ca ⎰	6		3		M⊙	2	3	5264.408	5264.395
Ca ⎱	8		3		⊙	1	2	5265.725	5265.727
			5		⊙		2		5265.789
(Ni?) ⎰									
Cr ⎰	4	R	2		⊙		1		5265.884
Fe	6		6		⊙″	1	8	5266.733	5266.729
E₂ Fe‡	8		8	d?	⊙″	1	16	5269.714	5269.722
Ca ⎱ §	10		4 ⎱		M⊙	2	3	5270.445	5270.448
E₁ ⎰			⎰	d	⊙″		12		5270.495
Fe ⎰	6		4 ⎰		M⊙		3		5270.533
Fe ⎱	3		3 ⎱		⊙″		6		5273.344
⎰			⎰	d	⊙′		5		5273.443
Fe ⎰	3		3 ⎰		⊙″		8		5273.554
? ⎱	?		2 ⎱						
Cr ⎰ ‖	5		2 ⎰		⊙″		11		5276.205
Co ⎰	3		1 ⎰	t					
Fe	4		5		· ⊙″		11		5281.968

* Components about 0.155 apart on photographic plates (J).

† Another set of measurements on photographic plates gives the components as 0.083 apart.

‡ Components about 0.088 apart on photographic plate. It is an exceedingly difficult double and it is possible that this doubleness of E₂ is really a case of the reversal of line in the Sun (J).

§ Components 0.077 apart as determined by another short series (R); 0.130 on photographic plates (J).

‖ Components of double about 0.075 apart on photographic plates. The fine side line to red is about 0.110 from the red component of double (J).

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	5		6		⊙″		11		5283.803
Fe	2		2		⊙″		12		5288.708
Cr	6	R	4		⊙″		12		5296.873
Cr	2		3		⊙″		9		5300.918
Fe	3		4		⊙″		10		5307.546
Fe? ⎫	⎫		4⎫		⊙		1		5316.790
1474 *		d	6⎬	d	⊙		7		5316.870
Co? ⎭	2⎭		3⎭		⊙		1		5316.950
Fe	9		8		⊙″		8		5324.373
Fe?	3		4		⊙′		9		5333.092
Ca	7		5		M⊙	1	4	5349.599	5349.623
Th†	75	t?			M	2		5350.670	
Fe–Ni‡	3 3		4		⊙1		8		5353.592
?			2		⊙		7		5361.813
Fe(Co)⎰§	1 3		1⎱	d	⊙		5		5363.011
? ⎱	?		3⎰		⊙1		1		5363.056
Fe	4		6		⊙″		8		5367.670
Fe	4		6		⊙″		8		5370.165
Ni ⎱‖	2		2⎱	d	⊙1		8		5371.686
Fe–Cr⎰	9 2		7⎰						
Fe	2		3		⊙″		9		5379.776
Fe	6		6		⊙″		11		5383.576
Fe	3		4		⊙″		11		5389.683
Fe	4		5		⊙″		11		5393.378
Fe	7		7		⊙″	1	12	5397.319	5397.346
Fe	7		7		⊙″	1	14	5405.979	5405.987
Cr	10	R	5		⊙″		7		5410.000
Fe⎱	4								
Va⎰		4	6		⊙″		12		5415.421
Va⎱	3								
Fe⎰	5		7		⊙″		10		5424.284

* The distance apart of the components of this 1474 line measured accurately is 0.146 by Crew, and 0.141 by Rowland. The coincidences with Fe and Co are very doubtful. The Co line comes more nearly between the two rather than coinciding with either (R).

A trial of substances in the arc gave the following results, iron, manganese, chromium, titanium and two different specimens of meteoric stones showed two faint lines having the same relative intensities with respect to each other as the components of 1474 in the solar spectrum, and either coincided with the components of 1474 or nearly so. When cobalt and nickel were tried, the lines were the same distance apart but the relative intensities were reversed, the red component being much the stronger.

With the best definition 1474 is a triple, or rather a double the red component of which has a weak side line to violet. The components as measured on a photographic plate are respectively 0.120 and 0.050 apart. The main components as determined by a series of measurements on photographic plates are 0.170 apart.

Probably the violet component is iron and the weak side line of the red component is cobalt, but the red component is unknown (J).

† With but little material in the arc this is a difficult triplet. The violet component is very strong; the red component about half as strong, and between them but nearer the red component is a very narrow line much weaker than either of the others (J).   ‡ Fine lines near to red.

§ Components about 0.110 apart on photographic plates (J).

‖ Red component itself is an exceedingly difficult double (J).

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc	Wave-length in Sun
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	5		6		⊙ "	I	9	5434.725	5434.742
Fe*	7		7		⊙ "	I	9	5447.116	5447.130
Fe?			3	d	⊙ '		I		5455.666
					⊙ '		8		5455.759
Fe	6		6		⊙		I		5455.826
Ni	3		I		⊙ '		7		5462.732
Fe	3		4		⊙ "		9		5463.174
Fe	3		4		⊙ "		10		5463.493
Fe	3		3		⊙ "		10		5466.608
Ni	15	R	4		⊙ "		10		5477.128
Fe	2		3		⊙ '		5		5487.968
Fe	3		4		⊙ "		8		5497.731
Fe	5		4		⊙ "		8		5501.685
Fe	5		4		⊙ "		8		5507.000
Ca	5	N	3		⊙	I	8	5513.127	5513.207
Mg†	10		7		⊙ "	4	8	5528.672	5528.636
Fe			2		⊙ "		8		5535.073
Fe	3		2		⊙ "		8		5543.418
Fe	3		2		⊙ "		9		5544.158
Fe‡	4		3		⊙ '		8		5555.113
Fe	6		5		⊙ "		8		5569.848
Fe	5		4		⊙ "		7		5576.319
Ca	6		4		M ⊙ "	2	9	5582.204	5582.195
Ca	10	R	6		M ⊙ "	2	9	5588.977	5588.980
Ca	5		4		M ⊙ "	2	5	5590.352	5590.342
Ca	7	R	5		M ⊙	2	5	5594.689	5594.695
Fe	3		2	d	⊙ '	I	2	5598.563	5598.555
Ca	7		4		⊙ '	2	4	5598.712	5598.715
Ca	5		4		M ⊙ "	2	4	5601.502	5601.501
Fe }	2		2 }						
Ca } §	6		3 }	t	⊙ '		10		5603.097
Fe }	5		5 }						
Fe	2		2		⊙ '		10		5615.526
Fe	2		6		⊙ '		10		5615.879
Fe‖	2		2		⊙ "		12		5624.253
Fe–Va‖	5 2		4		⊙ "		14		5624.768
Fe	2		3		⊙ "		5		5634.167
Fe	2		3		⊙ "		10		5641.661
Si			2		⊙		9		5645.835
Fe	2		4		⊙ '		9		5655.707
Yt?	I		4		⊙ "		9		5658.096
Fe	3		5		⊙ "		9		5662.745
Ti	3		2		⊙		8		5675.648
Fe	2		3		⊙ "		8		5679.249
Na	3		4		⊙ "		9		5682.861

* A difficult double (J).

† This Mg line is shaded to one side when there is much Mg in the arc and is therefore a poor metallic standard. The solar line corresponds to the extreme edge of this band-like line (R).

‡ Side line to violet.

§ This triplet is made up of close double and a line close to red stronger than either component of double; wave-length of components about 5602.995; 5603.080 and 5603.180 as measured on a photographic plate (J).

‖ Lines used by Peirce in his determinations of absolute wave-lengths.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Na			6		☉″		7		5688.434
Fe	4		5		☉″		8		5701.769
Si			5		☉″		4		5708.620
Fe			6⎱	d	☉		6		5709.616
Ni	5		5⎰		☉		8		5709.760
Mg*			6		M☉	4		5711.374	5711.318
Xi ⎱ Fe-Ti ⎰	5 / 3		5		☉″		10		5715.309
Fe			5		☉″		10		5731.973
Fe			3		☉		10		5742.066
Fe			4		☉″		10		5752.257
Fe			5		☉″		10		5753.342
Ni ⎱ ? ⎰			5		☉″		9		5754.884
Fe†			7		☉₁		8		5763.215
Si			5		☉″		6		5772.360
Fe			5		☉″		9		5775.304
Cu?Co?			7	d?	☉″		9		5782.346
Cr	6		4		☉″		9		5784.081
Cr	7		5		☉″		13		5788.136
Cr⎱ Fe⎰	10		7	d?	☉″		16		5791.207
?			4		☉″		10		5798.087
Fe			5		☉″		9		5798.400
Ni	7		5		☉″		8		5805.448
Fe			5		☉″		7		5806.954
Fe			5		☉″		14		5809.437
Fe‡			6		☉₁		14		5816.594
Ni	3		3		☉′		6		5831.832
Ba	10		5		☉″		14		5853.903
Ca§	10		7		☉′		14		5857.672
Fe			6		☽″		15		5859.810
Fe			6		☉″		16		5862.580
D₃He‖									5875.982
Fe ⎱¶ A(wv)⎰			6⎱ 4⎰	d	☉₁		11		5884.048
A(wv)			3		☉₁		8		5889.854
D₂Na			15		☉′		20		5890.182
Ni**	3	d?	4		☉		14		5893.098

   * This Mg line is shaded on one side, especially when there is much Mg in the arc and thus should not be used for a metallic standard (R).

   † There is a fine line near to violet.

   ‡ Line close to violet.

   § There is a Ni line near to red.

   ‖ This value of the *w-l* of D₃ is the result of three series of measurements made with a grating having 20000 lines to the inch, and is accurate to perhaps 0.02.

   Observations were made in the 1st. spectrum on both sides of the Sun. The line does not occur as a dark line in the solar spectrum; but is sometimes, if not always, present as a very weak bright line. This is shown by a study of the best photographs of this region of the solar spectrum. (J).

   ¶ A water-vapor line is toward the red about 0.080 from the Fe line and ordinarily forms a double with it.

   ** An exceedingly close equal double when there is very good definition. There is also a solar line near to the violet and a water-vapor line near to the red.

Elements.	In Arc. Intensity.	In Arc. Appearance.	In Sun. Intensity.	In Sun. Appearance.	Kind of Standard.	Weight. In Arc.	Weight. In Sun.	Wave-length in Arc.	Wave-length in Sun.
D₁Na			10		☉ʺ		20		5896.154
A(wv)} Fe? }			3} 1}	d?	☉₁		10		5898.395
A(wv)} Fe? }			5} 1}	d	☉₁		13		5901.681
Fe			5		☉ʺ		15		5905.895
Fe }* ?-(wv)}			4} 5}	d	☉ʺ		17		5914.384
Fe			5		☉ʺ		16		5916.475
A(wv)			6		☉ʺ		12		5919.855
Fe			6		☉ʺ		14		5930.410
Fe			6		☉ʺ		13		5934.883
Si			6		☉ʺ		14		5948.761
Fe			5		☉ʺ		12		5956.925
Fe			4		☉ʺ		12		5975.576
Fe			5		☉		13		5977.005
A(wv)			2		☉₁		1		5977.254
Fe			6		☉ʺ		6		5985.044
Fe			6		☉ʺ		7		5987.286
Fe			6		☉ʺ		7		6003.245
Fe			4		☉ʺ		3		6008.196
Fe			6		☉ʺ		6		6008.782
Mn	10		6		☉ʺ		5		6013.717
Mn	10		6		☉ʺ		8		6016.856
?}† Fe}			3} 5}	d	☉₁		6		6020.347
Mn	10		5		☉ʺ		6		6022.017
Fe			6		☉ʺ		8		6024.280
Fe			4		☉ʺ		7		6027.265
Fe			4		☉ʺ		8		6042.316
Fe			5		☉ʺ		9		6056.232
Fe			7		☉ʺ		13		6065.708
Fe			5		☉ʺ		13		6078.709
Fe			3		☉ʺ		12		6079.223
Fe			4		☉′		4		6102.408
Ca}‡ Fe}	10	R	6		☉ʺ		9		6102.941
?			4} 1}	d	☉₁		8		6103.449
Li	20				M	4		6103.812	
Ni	5		6		☉ʺ		8		6108.338
Ni	4		3		☉′		8		6111.287
Fe	5		6		☉ʺ		8		6116.415
Ca	15	R	9		☉ʺ		11		6122.428
Fe			8		☉′		9		6136.834
Fe-Ba	?-15		7		.☉ʺ		9		6141.934
Na			3		☉ʺ		5		6154.431
Na			5		☉ʺ		4		6160.970
Ca	15	R	10		☉ʺ		9		6162.383
Ca	6		6		☉ʺ		4		6169.260
Ca	7		7		☉ʺ		8		6169.775

* Components about 0.100 apart. Red component is partly solar and partly water-vapor. (J).

† Components about 0.200 apart.

‡ Components 0.100 apart.

Elements.	In Arc. Intensity.	In Arc. Appearance.	In Sun. Intensity.	In Sun. Appearance.	Kind of Standard.	Weight. In Arc.	Weight. In Sun.	Wave-length in Arc	Wave-length in Sun
Fe			6		⊙"		8		6173.554
Ni	5		6		⊙"		8		6177.028
Fe			6		⊙"		8		6180.419
Ni	4		6		⊙"		9		6191.397
Fe			8		⊙"		10		6191.770
Fe			6		⊙"		10		6200.533
Fe			6		⊙"		9		6213.646
Fe			6		⊙"		10		6219.493
Fe–Va	?-6		7		⊙"		12		6230.946
?			4		⊙"		8		6237.529
Fe			7		⊙"		9		6246.530
Fe			7		⊙"		9		6252.776
Fe*			7		⊙"		9		6254.454
Ni ⎫ Fe ⎭	7 ?		6		⊙"		8		6256.574
Ti	5		2		⊙"		9		6261.316
Fe			5		⊙"		11		6265.347
Fe			3		⊙"		10		6270.439
α A(O)†			4	d	⊙"		9		6278.289
A(O)			2		⊙'		7		6281.374
A(O)‡			2		⊙'		5		6289.608
A(O)§			3		⊙		6		6293.152
A(O)			3		⊙"		7		6296.144
Fe			7		⊙"		7		6301.719
Ni	6		4		⊙"		7		6314.874
Fe‖			3		⊙₁		5		6315.541
Fe–(Ca)			6		⊙"		14		6318.242
Fe			5		⊙"		13		6322.912
Fe			6		⊙"		12		6335.550
Fe			6		⊙"		12		6337.042
Fe			5		⊙"		6		6344.370
Fe¶			5		⊙		8		6355.259
Fe			6		⊙"		8		6358.902
Ni	5		2		⊙₁		2		6378.461
Fe			4		⊙"		6		6380.951
Fe			7		⊙"		9		6393.818
Fe			8 ⎫		⊙₁		5		6400.200
Fe			3 ⎭		⊙₁		6		6400.509
Fe			6		⊙"		8		6408.231
Fe			7		⊙"		10		6411.864
Fe			5		⊙"		8		6420.171
Fe**			6		⊙		10		6421.569
Fe			6		⊙"		10		6431.063
Cd					M	I		6438.680	
Ca	10	R	7		⊙"		11		6439.298
Ca	5		6		⊙"		6		6450.029

* This is a difficult double or there is a side line close to violet.

† Chief line in the α group. It is a very close atmospheric double with some weak atmospheric lines to red and a faint water-vapor line near to violet (J).

‡ First line of the first pair of lines in the tail of the α group.

§ Second line in the second pair of the tail of α. Faint line to violet.

‖ Side line to red.

¶ Faint line near to red.

** There is a Ni line to red.

| Elements. | In Arc. | | In Sun. | | Kind of Standard. | Weight. | | Wave-length in Arc. | Wave-length in Sun. |
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Ca⎰	10	R	9⎰	d	☉ ″		9		6462.835
Fe⎰	?		3⎰						
Ca	5		5		☉ ″		7		6471.881
A(wv)			1		☉		6		6480.264
?			4		☉ ″		8		6482.099
Ca	8		6		☉ ″		10		6494.001
Fe			7		☉ ″		9		6495.209
Ca	5		5		☉ ″		10		6499.871
?	6		4		☉		7		6516.315
Fe			4		☉ ′		10		6518.594
A(wv)			1		☉		7		6532.546
?			3		☉ ″		12		6534.173
Ti⎰	3		6		☉ ″		11		6546.486
Fe⎰	?								
A(wv)			2		☉		6		6552.840
C H			30		☉ ″	.	13		6563.054
Fe			6		☉ ″		13		6569.461
A(wv)			1		☉		6		6572.312
?			2		☉		5		6574.477
Fe*			4		☉ 1		7		6575.179
Fe			5		☉ ″		11		6593.161
Fe			4		☉ ″		12		6594.115
Fe			4		☉ ″		9		6609.354
Fe†			3		☉		7		6633.992
Ni	5		5		☉ ″		10		6643.882
?		.	1⎰		☉ ″		4		6663.525
Fe			4⎰	d	☉ ″		6		6663.696
Fe			5		☉ ″		10		6678.232
?			2		☉		10		6703.813
?			3		☉		12		6705.353
Li‡	75	t?			M	3		6708.070	
Ca§	10		5		☉		10		6717.934
?			3		☉		10		6722.095
Fe			3		☉		7		6726.923
Fe			4		☉ ″		12		6750.412
Fe			2		☉ ′		7		6752.962
Ni	5		4		☉ ″		9		6768.044
Ni	2		3		☉ ′		10		6772.565
Fe			1		☉		5		6787.137
·Fe			2		☉ ′	.	6		6807.100
Fe			3		☉ ″		8		6810.519
Fe			2		☉ ′		5		6820.614
Fe			2		☉ ′		7		6828.850
Fe			3		☉ ′		6		6841.591
Fe			3		·☉ ′		5		6843.908
Fe			3		☉ ′		10		6855.425
A[O]‖			3		☉ ′		11		6867.461

* There is a water-vapor line near to violet.

† There is a faint line near to each side.

‡ With but little material in the arc this is a difficult triplet. The violet component is very strong, the red component about half as strong, and between them but nearer the red component is a very narrow line much weaker than either of the others (J).

§ Side line to violet.

‖ This line and the following one are at the beginning of the head of B. There is a fine line midway between them.

Elements.	In Arc. Intensity.	In Arc. Appearance.	In Sun. Intensity.	In Sun. Appearance.	Kind of Standard.	Weight. In Arc.	Weight. In Sun.	Wave-length in Arc	Wave-length in Sun
A[O]*			3		⊙'		11		6867.800
A[O]			1		⊙₁		2		6868.124
A[O]			6	d	⊙		2		6868.393
A(O)			1}3}	d	⊙₁		3		6868.779
A(O)}			4}	d	⊙'		5		6869.141
A(O)}			4}		⊙'		5		6869.347
B A(O)†			4}4}	d	⊙"		12		6870.186
A(O)			5		⊙'		6		6871.179
A(O)			5		⊙'		6		6871.527
A(O)			5		⊙"		5		6872.493
A(O)			5		⊙"		4		6873.076
A(O)			5		⊙"		5		6874.039
A(O)			5		⊙"		5		6874.884
A(O)			5		⊙"		9		6875.826
A(O)			5		⊙"		7		6876.957
A(O)			5		⊙"		7		6877.878
A(O)			5		⊙"		11		6879.294
A(O)			3		⊙"		11		6880.176
Cr	1		1		⊙		5		6881.970
Cr	2		1		⊙		5		6882.772
Cr	3		1		⊙		5		6883.318
A(O)‡			4		⊙"		13		6884.083
1 {A(O)			5		⊙"		12		6886.008
A(O)			5		⊙"		12		6886.987
2 {A(O)			5		⊙"		5		6889.194
A(O)			5		⊙"		5		6890.149
3 {A(O)			6		⊙"		5		6892.614
A(O)			6		⊙"		5		6893.559
4 {A(O)			6		⊙"		7		6896.292
A(O)			6		⊙"		8		6897.195
5 {A(O)			6		⊙"		6		6900.199
A(O)			6		⊙"		8		6901.113
6 {A(O)			6		⊙"		5		6904.358
A(O)			6		⊙"		5		6905.263
7 {A(O)			6		⊙"		5		6908.785
A(O)			6		⊙"		9		6909.675
8 {A(O)			5		⊙"		5		6913.454
A(O)			5		⊙"		4		6914.328
Ni	5		3		⊙'		4		6914.819
?			2		⊙'		5		6916.957
9 {A(O)			4		⊙"		5		6918.363
A(O)			4		⊙"		9		6919.245
10 {A(O)			3		⊙"		8		6923.557
A(O)			3		⊙"		11		6924.420
11 {A(O)			2		⊙'		5		6928.992
A(O)			2		⊙'		8		6929.838
12 {A(O)			1		⊙		4		6934.646
A(O)			1		⊙		5		6935.530

* This line and the preceding one are at the beginning of the head of B. There is a fine line mid way between them.
† The principal line in the head of B. It is a difficult double.
‡ Single line at the beginning of the tail of B.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
A(wv?)			8		⊙"		10		6947.781
A(wv?)			2}	d	⊙₁				
A?			1}				4		6953.838
A(wv)			8		⊙"		12		6956.700
A(wv?)			3		⊙		10		6959.708
A(wv?)			6		⊙		12		6961.518
?			2				5		6978.655
A(wv)			5		⊙'		10		6986.832
A(wv?)*			5		⊙		7		6989.240
A(wv?)†			5	d?	⊙₁		6		6999.174
?			4		⊙		3		7000.143
?			5		⊙₁		5		7006.160
?			3		⊙		6		7011.585
A(wv?)			3}		⊙₁		5		7016.279
A(wv?)			6}		⊙₁		9		7016.690
?			4		⊙₁		1		7023.225
?			3		⊙₁		7		7023.747
?			3	d?	⊙₁		2		7024.988
?			1}		⊙₁		1		7027.199
?			3}				7		7027.726
?			6		⊙'		8		7035.159
?			2				6		7038.470
?			4		⊙		10		7040.058
?			4		⊙'		5		7090.645
?			6		⊙'		5		7122.491
?			1				4		7147.942
?			7		⊙'		4		7148.427
?			3				5		7168.191
A(wv)?			3				6		7176.347
A(wv?)			4				7		7184.781
A(wv?)			5	d			6		7186.552
A(wv)			7				3		7193.921
A(wv)			10		⊙		5		7200.753
A(wv)			10		⊙		5		7201.468
A(wv?)			6				4		7216.812
?			8		⊙		5		7223.930
?			6				4		7227.765
?			3				3		7232.509
?			8		⊙		4		7233.171
A(wv)			4				5		7240.972
A(wv)			15		⊙		4		7243.904
A(wv)?			4				2		7247.461
A(wv)?			8				3		7264.851
A(wv)?			8				3		7265.833
?			3	d			2		7270.205
A(wv)?			8				4		7273.256
A(wv)?			6				3		7287.689
A(wv)?			10	d?			3		7290.714
A(wv)			4				3		7300.056
A(wv)?			7				4		7304.475
A(wv)?			5	d?			4		7318.818
?			2				3		7321.056

* There is a line towards the violet.
† There is a line close to violet.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
?			2				3		7331.206
?			7				2		7389.696
?			6				2		7409.554
?			6				3		7446.038
?			6				2		7462.609
?			6				3		7495.351
?			6				3		7511.286
?			3				1		7545.921
A(O)*							4		7594.059
A(O)†			10		⊙ ′		5		7621.277
1 { A(O)			12		⊙		4		7623.526
A(O)			12		⊙		4		7624.853
2 { A(O)			14		⊙		3		7627.232
A(O)			14		⊙		3		7628.585
7 { A(O)			14		⊙		3		7659.658
A(O)			14		⊙		3		7660.778
10 { A(O)			8				3		7665.265
A(O)			8				3		7666.239
11 { A(O)			7				3		7670.993
A(O)			7				3		7671.994
?			7				1		7699.374
?			4				1		7714.686

* Beginning of the head of A. Outside edge.
† Single line at the beginning of the tail of A.
NOTE—A(wv) denotes a line due to absorption by the water vapor in the Earth's atmosphere; A(O), a line due to the oxygen in the atmosphere.

NOTE ON THE SPECTROSCOPY OF SULPHUR.*

B. HASSELBERG.

In the January number of this journal Mr. Ames gives under the title "On the probable spectrum of Sulphur," the description of some ultra-violet series of spectral lines, which he has observed in vacuum tubes filled with hydrogen, and whose peculiar character made it quite certain that they could have no connection with the spectrum of this gas. The lines in question formed groups similar in structure to the B group of the solar spectrum, in some cases overlapping one another. It seems, then, that in a spectroscope of small dispersive power these groups would have presented themselves as flutings of the usual description, with decreasing intensity towards the red, because the head of each series was situated towards the shorter wave-lengths. On ac-

* Communicated by the author.

count of the special experimental disposition used for the purifi-
cation of the hydrogen, in which sulphur was employed to
stop the mercury vapor, Mr. Ames thinks that the mentioned
series of lines or flutings is probably to be considered as the
spectrum of sulphur. This surmise may indeed be agreed to, be-
cause the low temperature spectrum of this metalloid consists
in the visual part, as is well known, of precisely such flutings,
whose strong edges are turned towards the violet with decreas-
ing intensity in the opposite direction. The observed groups
would then form the hitherto unknown ultra-violet continuation
of this spectrum. There only remains to be explained the curious
circumstance that the groups in question showed themselves only
in one series of observations, but could not subsequently be repro-
duced in any way whatever. This induces me to call attention
to an investigation on the spectrum of hydrogen, in which I ob-
served the high temperature spectrum of sulphur in a vacuum
tube under conditions which seem to point to a possible origin of
the sulphur spectrum in the present case other than the sulphur
employed in purifying the gas.

In the year 1868 Wüllner* published a paper on the spectra of
the gases in which he describes a new and peculiar spectrum ob-
served by him in highly evacuated hydrogen tubes. Owing to an
unsatisfactory comparison with other spectra then known Wüll-
ner was misled to consider this new spectrum as a second line
spectrum of hydrogen, although its close agreement with the
line spectrum of sulphur as observed by Plücker was shortly
afterwards pointed out by Angström,† and in the researches on
the spectroscopy of hydrogen by Salet no such spectrum was
found. From these circumstances it then seemed almost certain
to every spectroscopist but Wüllner, that the new spectrum
could have no connection with hydrogen, but must probably
be due, either to a contamination of the gas by the sulphuric
acid employed to dry it, or to some other cause. That the latter
was in all probability the case is proved by a series of experi-
ments executed by me in 1880‡, in which the same spectrum was
obtained in highly evacuated tubes filled with common air.
By these experiments it was demonstrated beyond every doubt
(1) that the spectrum was due to sulphur, and (2) that the sul-
phur originated in the vaporization of the glass under the heat-
ing power of the very strong condensed induction sparks em-

* Pogg Ann. Bd. CXXXV. p. 497.
† C. R. Vol. LXXIII, p. 368.
‡ Bulletin de l'Académie de St. Petersbourg, T. XXVII, p. 97.

ployed. The first conclusion was arrived at by the close agree-
ment of the wave-lengths and intensities of about 40 lines in the
new spectrum with the measurements of the high temperature
spectrum of sulphur by Plücker after reduction to wave-lengths,
The correctness of the second inference followed from the fact,
that the spectrum could be obtained only in one specimen of cap-
illary glass-tube, but not in others tried under precisely the same
experimental conditions. In this way not only the alleged
second line spectrum of hydrogen was definitely abolished but
also a similar line spectrum of oxygen, which Wüllner had at-
tributed to this gas, was found to be nothing else than the spec-
trum of chlorine vaporized from the glass by the heat of the
electric discharges.

From the above it seems to me that the spectrum observed by
Mr. Ames, if indeed a part of the low temperature spectrum of
sulphur, was most probably due to the vaporization of the special
glass tube employed, in which case the impossibility of obtain-
ing it in other tubes of different composition is satisfactorily ex-
plained. In order to test this supposition more closely the first
thing to be done is obviously an exact investigation on the fluted
spectrum of sulphur. Of this spectrum very little is as yet known,
for the researches of Plücker, Hittorf and Salet are indeed so im-
perfect that from them nothing but the existence of it can be con-
cluded. This is for the visual part, whereas the ultra-violet
region is completely unknown. Should a comparison of Mr.
Ames' spectrum with the sulphur spectrum thus examined prove
their identity, then the exceptional appearance of it in only one
case can, I think, be explained on the same ground as the presence
of the line spectrum in the hydrogen tubes of Wüllner.

STOCKHOLM, Feb. 10th, 1893.

NOTE ON THE SPECTRUM OF NOVA AURIGÆ.[*]

WILLIAM HUGGINS.

It may perhaps be desirable on account of the near positions of
the bright bands in the spectrum of Nova Aurigæ to those of the
nebular lines, to anticipate the account of our observations of the
present spectrum of this star so far as to state at once the results
of an examination of the character of the brightest band, on the
nights of Feb. 7th, 8th and 10th.

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[*] Communicated by the author.

When the band was observed in the spectrum of the second
order of a 4-inch Rowland grating, 14438 lines to the inch, with
a magnifying power of 23 diameters, it was resolved into a long
group of lines extending through about 15 tenth-meters. The
lines appeared more or less bright upon a faintly luminous back-
ground which could be traced a little beyond the lines at both
ends of the group. Two lines, the brightest in the group and
about equally bright, formed the termination of the group
towards the blue; and a line nearly as bright as these was seen
about the middle of the group.

The group is therefore brighter at the blue end, but it does not
possess any of the features of a fluting.

No contrast in the spectroscope could well be more striking
than that which this extended group of lines forms with the nar-
row and defined principal line in the nebula of Orion.

UPPER TULSE HILL, London.

   Feb. 11th, 1893.

VISUAL OBSERVATIONS OF THE SPECTRUM OF β LYRÆ.*

JAMES E. KEELER.

The variable star β Lyræ has been an object of extreme interest
to students of stellar spectroscopy ever since the discovery of
bright lines in its spectrum by Secchi, but until recently no obser-
vations have been made with telescopes of adequate size. When
I began spectroscopic work at the Lick Observatory in 1889,
with the advantage of the great light-gathering power of the
thirty-six-inch refractor, this star was naturally one of the first
that engaged my attention, and I observed it frequently in the
course of other work. The object of the observations was to
connect possible changes in the spectrum of the star with its
period of light-variability. Previous attempts in this direction
had brought out little more than the fact that such a connection
probably exists, but I hoped·for a greater measure of success, on
account of the more powerful means at my command and the
uniformity of atmospheric conditions at Mt. Hamilton during
the summer months. After a large number of observations had
been made, without reference to the star's period, they were
platted on the light curve of the star. The recorded appearances
of the spectrum were in some degree contradictory. Certain

* Communicated by the author.

definite results were indeed obtained, but I was unable to give a satisfactory explanation of them, and awaited a longer series of observations, which was left incomplete when I withdrew from the Observatory. These observations have never been published, and it is not likely that they will be continued, as it has been shown that visual observations cannot in general compete with photographic methods applied to the same or even to a much smaller telescope. They have, however, some features of interest, since they relate chiefly to a part of the spectrum that can not be photographed readily and hence they may supplement photography in arriving at a complete explanation of the complex phenomena presented by this star. The remarkable results obtained with the aid of photography by Pickering* and more recently by Pelopolsky†, leave little doubt that such an explanation will soon be forthcoming. I have therefore, with Professor Holden's permission, made an abstract of these observations for the purpose of the present article.

A few remarks on the instruments and methods are necessary. The spectroscope commonly employed was a small instrument belonging to the Chabot Observatory. The collimator and observing telescope of this spectroscope have each a focal length of ten inches. The observing telescope is fixed in a position corresponding to a deviation of about $56°$, which is greater than the minimum deviation of any part of the visible spectrum, and the spectrum is brought into the field by rotating the prism. In these observations the prism was used in the position which gave the least dispersion, *i. e.*, with the refracting edge turned toward the observing telescope. No measurements can be made with this instrument, and the positions of lines which are given in some of the observations were determined with the large spectroscope described in the February (1892) number of this journal. It was found that the relative visibility of lines in different parts of the spectrum depended greatly upon the arrangement of apparatus employed, a fact which will be readily understood on considering the chromatic aberration of the great telescope. The color curve rises rapidly above F, and the width of the spectrum at this point varies in a corresponding manner. An abnormal distribution of light is thus produced which interferes greatly with the observation of a faint line. Applying greater dispersion would ten to obviate this difficulty, and hence might make a line in the blue more conspicuous, while a line in the yellow, where the sides of the spectrum are nearly parallel, might become fainter, especially

* *A. N.* 3051.   † *A. N.* 3129.

if it were broad and diffuse.   Hence the necessity of always using
the same instrument for purposes of comparison.

In the observations which follow, the spectrum is frequently
described as having the "usual appearance," and it is necessary
to define what is meant by this term.   With the small spectro-
scope above mentioned, the continuous spectrum of β Lyræ was
beautifully bright, showing vivid colors.*.   It extended from
about C to above F, where, with the usual adjustment in the fo-
cal plane of the great telescope, it spread out into a broad fan-
shaped sheaf of light, and was lost.   The C and F lines were
bright and easily visible, particularly C, and broader than the
same lines in γ Cassiopeiæ.   The most conspicuous line in the
spectrum was D_3, a very bright and broad line.   Just below D_3
the dark D line was always seen, as a strong dark shade, so
blurred that the component lines could seldom be distinguished.
Next to the lines above mentioned the most conspicuous bright
line was a faint bright line in the greenish yellow at about λ 567.
Below F was a rather faint greenish-blue line at about λ 502.

The variations in the brightness of these lines were found to be
most perceptible in the case of the two last mentioned, probably
because they were nearer the limit of visibility than the others,
and anything unusual in their appearance was therefore carefully
noted.   For purposes of reference I have called these two lines *d*
and *f* respectively.

For the convenience of the reader I have given the position
which each observation occupies when platted on the light-curve
of the star, but it will be remembered that the platting was a
subsequent process, and that all the estimates of the appearance
of the spectrum were unbiased by any previous knowledge of
the phase of the star at the time of observation.

OBSERVATIONS.

1889, June 6 and June 7.   The positions of the hydrogen lines
and D_3 line were measured with the large spectroscope and 60°
prism and the lines identified.   The dark shade at D was esti-
mated to begin one width of the broad D_3 line below the less re-
frangible edge of the latter.

June 13.   One day past principal minimum.   C bright, F rather
dim, *d* is distinct, but not very bright.   D broad and black; could
not be seen double.   There appeared to be a fine bright line close
to D_3 on the more refrangible side, independently noticed by Pro-
fessor Holden (see figure, No. 2).

* The bright C and F lines are easily seen in the spectrum of Pleione, but
there is no line visible at the place of D_3.

PLATE XXII.

1

2
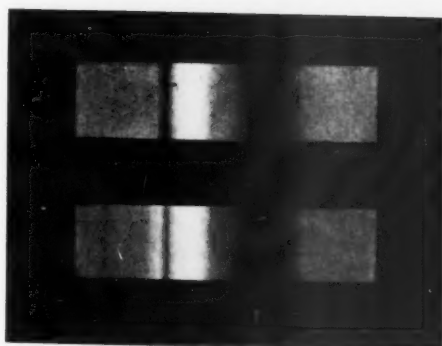
The D$_3$ Line in the Spectrum of β Lyræ.

1.   Nov. 14 and 15, 1889.
2.   June 13, 1889.

June 14. Two days past principal minimum. D_3 very bright, D dark, C quite bright, F perhaps fainter than usual, d well seen. The spectrum is probably full of bright lines, which would be well seen if there were more light. Suspected dark band below C (very doubtful).

June 15. First maximum. Spectrum brilliant. C and F much brighter than usual, D_3 very bright, but I cannot say whether it is brighter than usual. The continuous spectrum extends a considerable distance below C. D dark, about as usual. At times I think I can see a fine bright line in or just below it. This may be due to contrast, or possibly it is a reversal of the line. d is easily seen, so that the focus can be adjusted by it. Other bright lines at λ 573 and λ 551 (estimated positions), and some others still fainter. A dark band was suspected below C (very doubtful.)

June 16. One day past first maximum. Spectrum same as last night.

June 18. Secondary minimum. Spectrum about as usual. Hydrogen lines bright. The bright line called f seen for the first time. With this spectroscope it is as far below F as d is above D_3.

June 20. One and one-half day before second maximum. The position of d was measured with the large spectroscope and 30° prism. The distance between D_3 and d was measured with the micrometer and with the circle, and was found to be 3′ 4″, making the wave-length of $d = 5670$.

The distance between the D_3 line and the estimated center of the dark shade D was measured with the micrometer, and found to be 18″. The true interval between D and D_3, from the curve for the 30° prism, is 15″.

June 21. One-half day before second maximum. Spectrum bright, hydrogen lines also bright, particularly C. D_3 and D as usual. f seen without much difficulty.

June 22. One-half day past second maximum. Spectrum about as usual,—perhaps the hydrogen lines are somewhat brighter than the average. d and f seen. Dark bands somewhere between F and f almost certain.

June 28. First maximum. Spectrum bright, but blurring badly. The hydrogen lines appeared to be somewhat brighter than usual the D line perhaps darker, d quite bright.

June 29. One day past first maximum. Spectrum same as last night. Seeing bad.

July 2. Secondary maximum. One observation with the same spectroscope on the 12-inch equatorial. D_3 seen easily and the hydrogen lines with difficulty.

July 4. One-half day before second maximum. Spectrum as usual.

July 5. One-half day after second maximum. Spectrum bright and as usual.

July 11. First maximum. Spectrum bright, and as usual. D₃ brilliant, *d* easily seen, *f* seen with difficulty. No new lines.

July 12. One day past first maximum. Spectrum about as usual, perhaps brighter than the average.

July 18. One day past second maximum. About the same as usual; lines quite bright.

July 19. One half day before principal minimum. Spectrum dimmer than usual; D₃ was dimmer, and D darker; C easily seen, F a little difficult. Saw *f*, but thought there were dark absorbtion lines near it.

July 25. One-half day past first maximum. Spectrum bright, and the lines seemed to be unusually brilliant. *d* very distinct. D was distinct, but apparently not quite so dark as usual. The seeing was bad, and the lines were very much blurred.

July 26. One day before secondary minimum. Spectrum about as usual.

Aug. 1. One day before principal minimum. Spectrum nearly as usual. D₃ rather dim, and D unusually dark.

Aug. 2. One-half day past principal minimum. The spectrum has an unusual appearance to-night. The seeing is good. The D₃ line appears particularly sharp and bright, and the D line unusually dark. The hydrogen lines are bright, and F is remarkably conspicuous. Just below F, between that line and *f*, is a black line,* quite easy to see. *f* (bright) seen occasionally. Other absorption bands seen indistinctly in this vicinity. *d* absolutely invisible.

Aug. 9. Secondary minimum. Spectrum about as usual, except that *f* is uncommonly bright and distinct, being nearly equal to *d*, which is seen easily. Below *f* and close to it, appears to be a faint dark line or band.

Aug. 16. One-half day past principal minimum. D₃ line sharp and bright, D darker than usual, F rather bright. Black line noted on Aug. 2 was seen again. *d* not seen; perhaps it becomes invisible at the same time that the black line appears.

Aug. 21. One day before secondary minimum. The hydrogen lines do not seem quite so bright as usual. D₃ about the same, but D is not so dark. *d* is quite bright, and *f* is seen without difficulty. Other bright lines also seen. No dark lines below F.

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* Subsequently found to be at λ 492; called *g*.

Aug. 22. Secondary minimum. About the same as last night, d perhaps brighter, f fairly well seen. No dark lines below F.

Aug. 29. One-half day past principal minimum. Unusual appearance of spectrum. D_3 is dim, but sharper than usual, D dark and strong. Black line below F (g, at λ 492) easily seen. d and f invisible.

Aug 30. One and one-half day past principal minimum. Spectrum seems bright, but the bright lines are dim. D_3 dimmer than I have yet seen it, sharp and narrow. F seen with difficulty, and black line (g) seen, but it is not so strong as it was last night. C quite dim, f not seen, d just visible.

Sept. 5. One day past secondary minimum. Hydrogen lines quite bright, d seen easily. It is nearly as bright as I have seen it; about as broad as D_3 but very much fainter. f seen with difficulty. D_3 bright and broad, D not very dark. No black lines below F.

Sept. 6. One day before second maximum. Spectrum about as usual. d easily visible, f seen with difficulty. No absorption lines in blue or green. The D line of average depth. Comparison with a spirit lamp showed that it was apparently coincident with the double line of sodium.

Sept. 12. Two days past principal minimum. Spectrum bright, but lines rather dim. F rather difficult; at times suspected a dark line close to it, and just above. D_3 somewhat dim, and sharp. d is easy, D strong and dark, f not seen. C is comparatively brighter than F.

Sept. 14. One-half day past first maximum. About as usual.

Sept. 19. One day before second maximum. About as usual. D rather faint, d bright, f easy.

Sept. 27. One-half day past first maximum. About as usual, D_3 fairly bright and D rather faint. d and f seen. Sky hazy, but spectrum pretty bright.

Sept. 28. One and one-half day past first maximum. About the same as last night.

Sept. 30. One-half day past secondary minimum. The same as usual.

Oct. 3. Second maximum. Hydrogen lines brighter than usual, D_3 bright and sharp, D dim, d bright and rather broad, f bright and easy. Whole spectrum bright.

Oct. 4. One day past second maximum. Lines bright, but not quite so bright as on the 3d. d and f seen easily.

Oct. 10. One day past first maximum. Spectrum about as usual, and bright. D dim, f seen, d as bright as I have ever seen it.

Oct. 11. Two days past first maximum. Just about the same as last night.

Nov. 7. One-half day before secondary minimum. With the large spectroscope, determined the position of the bright line *f*, by measuring its distance from the F line with the micrometer. A compound prism giving a dispersion of 9° from B to Hγ was used, set to minimum deviation for F. The measured distance was 14.010 rev. Subsequent measures in the solar spectrum for reduction give for the place of *f*, λ 5015.

With the compound prism, used for the first time on this star, the lines in the upper part of the spectrum were more easily observed than with the small spectroscope.

Nov. 8. One-half day after secondary minimum. Same apparatus as last night. *f* measured again, but roughly, on account of thin clouds. A new bright line was seen between *f* and F. It was subsequently found to be the bright companion line of *g*.

Nov. 9. One and one-half day after secondary minimum. Spectrum bright, *d* and *f* brighter than the average.

Nov. 13. One day before principal minimum. Definition bad, but lines fairly distinct at times. Lines not very bright. *d* and *f* seen.

Nov. 14. Principal minimum. Spectrum dim, and of unusual appearance. The D lines are strong, dark and hazy. The interval between the center of the dark shade and the center of the D_3 line was measured with the large spectroscope and compound prism, and found to be 0.623 rev. of the micrometer = 13.75 tenth-metres. This is less than the distance in the solar spectrum (17.08 tenth-metres).* The different measures are, however, very accordant. According to a single comparison with the sodium lines furnished by a spirit lamp, the D lines of the star were displaced toward the violet by about two tenth-metres. The comparison was only a rough one.

Close to D_3 on its more refrangible side is a fine dark line (see figure, No. 1). Its distance from the center of D_3, as measured with the micrometer, was 0.179 rev. = 3.95 tenth-metres. It is remarkable that this dark line is distant from D by an interval (17.70 tenth-metres) which very nearly represents the normal distance of D_3 from D.

Below F were seen two black lines, each with a bright line adjoining it on its less refrangible edge. The bright lines were somewhat like flutings, being sharply bounded by the dark lines above, and fading off more gradually on the lower side. One of

* Scheiner's Spectralanalyse der Gestirne, p. 198.

these lines was *f*, the other the black line *g* seen on former occasions.

Measures with the micrometer gave the following results:

Bright line, F		$\lambda = 4861.7$ (Assumed).
1st line, (*g*)	{ Dark line	4920.8
	{ Bright line	4925.1
2nd line, (*f*)	{ Dark line	5013.2
	{ Bright line	5018.4

Nov. 15. One day past principal minimum. The spectrum is dim. D_3 has the same appearance as last night. D very dark; lines seen separately at times. Sharp dark line above D_3, as seen last night. *d* invisible, F dim. The absorption lines with bright edges measured last night are still visible, but now the dark lines are very prominent, whereas last night the dark lines were less conspicuous than the bright borders. One new line (*e*) of the same kind was seen below *f*.

The positions of the dark lines were determined with the micrometer.

Bright line, (F)	$\lambda = 4861.7$ (Assumed)
First dark line below, (*g*)	4917.3
Second dark line below, (*f*)	5011.9
Third dark line below, (*e*)	$5165 \pm$ (difficult).

The bright lines, bordering the above dark lines on their less refrangible sides, were not measured.

Nov. 21. One day after secondary minimum. Spectrum about as usual. *d* and *f* seen. The star is now getting too low for observation.

1890. May 8. One day after secondary minimum. Spectrum about as usual.

May 16. One day before first maximum. Lines rather dim. Dark lines seen below F. *d* visible; at times I suspected a dark line on its less refrangible side.

July 19. Two days past principal minimum. Spectrum not very different from its usual condition. Hydrogen and D lines bright; *d* seen, but it is not very bright. Traces of the dark lines below F.

Sept. 11. One day past first maximum. Spectrum bright, and all bright lines conspicuous.

Sept. 12. One day before secondary minimum. Spectrum just about the same as last night.

With large spectroscope noticed that *d* was barely visible with the prism set to minimum deviation, but that it was easily seen when the prism was turned so as to diminish the dispersion. This shows that *d* is a broad line.

1891. May 7. Second maximum. Continuous spectrum and bright lines are bright, D is not very dark, and hazy. *d* visible.

An attempt was made to measure the position of the D$_3$ line with a diffraction grating on the large spectroscope, but the line was very dim, and too broad and diffuse for measurement.

The observations given above are to some extent contradictory, but this is by no means surprising, considering the fact that the estimates of brightness were made with no better guide than the remembrance of a previous appearance of the spectrum. Making all due allowance for errors arising from the lack of a suitable standard of reference, I think that a connection between the changes in the spectrum and the light period of the star is fairly established by the observations. The conclusions which it seems to me may be drawn from a consideration of all the observations are as follows :

1. In the spectrum of *β* Lyræ the bright hydrogen lines C and F, the bright D$_3$ line, and the dark D lines are always visible with a telescope as large as the Lick refractor.* Certain fainter bright lines are visible except at the time of a principal minimum.

2. The variations in the light of the star are principally due to changes in the brightness of the continuous spectrum.

3. The bright lines are brightest when the continuous spectrum is brightest. This is the case in most of the observations. certain exceptions may possibly be real, in which case they would indicate either irregular variations of brightness, or a variation having a period different from that of the star, or they may be due to errors of estimation arising from the diminished brightness of the continuous spectrum at the time of a principal minimum.

4. The bright lines are broad and diffuse, particularly when the star is at a maximum. The D lines are very hazy, so that the components are hardly distinguishable.

5. During the greater part of the period of the star no remarkable changes occur in the appearance of the spectrum. The observations fail to show any connection between changes in the spectrum and the secondary minimum of the star.

6. The most remarkable changes take place at the time of a principal minimum. The bright lines become dimmer, and perhaps sharper. The fainter bright lines disappear. The D lines become darker. Strong absorption lines appear on the more refrangible side of certain bright lines in the green, the separation

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* Strictly speaking, the conclusion is, of course, that these lines were visible during the period covered by the observations. Some remarks on this subject are given further on.

of the dark and bright lines being at least five tenth-metres. Other bright lines are perhaps similarly affected. A narrow dark line appears above the D_3 line at the same time. Shortly before the first maximum is reached the dark lines disappear.

These conclusions are decidedly at variance with older observations, and I have gone over some of the latter rather carefully, particularly those of Herr von Gothard in *A. N.* 2651, platting them on the light-curve of the star in order to see if any correspondence with my own observations could be found, but I must say with very unsatisfactory results. Certainly the spectrum of β Lyræ, during the time covered by my observations, exhibited no such extreme and erratic changes as those described by Herr von Gothard. Without denying the possibility of much greater changes than those which I observed, I think that some of the extreme variations formerly recorded may be attributed to the small size of the instruments employed. In the case of a line nearly at the limit of vision, slight fluctuations in its brightness, or slight variations of other conditions, would make all the difference between visibility and invisibility. With a larger telescope than the Lick refractor, I have no doubt that the line I have called d would be seen even at the time of a principal minimum. At the same time, I am free to confess that this explanation seems to be insufficient. Future observations with large instruments will no doubt decide the matter, as it is highly improbable that irregular variations, if they formerly existed, should have come to a sudden end.

I have now no doubt that the phenomena I observed are only part of a much more complex series of changes, which could not be completely followed with the method of observation I employed. It appears from the photographic researches of Pickering and of Belopolsky, that the principal dark lines oscillate to and fro across the corresponding bright lines, so that the partial disappearance of the latter is due to the superposition of the two sets of lines. On comparing Herr Belopolsky's table of positions of the different components of the F line, in *A. N.* 3129, with the light curve of the star, I find that there are only three observations made near the time of a principal minimum. Of these only one, that of Sept. 27, 1892, was made at a phase for which I have corresponding observations ($1\frac{1}{2}$ day past the principal minimum), and the agreement in this case is complete. In most of the other cases, which do not fall near the time of a principal minimum, the dark line is superposed on the bright one, and doubtless would have escaped detection by visual means. On

one or two occasions my notes record the fact that a dark line
was suspected on the less refrangible side of a bright one, but I
cannot decide from Herr Belopolsky's table whether these obser-
vations are in agreement with his own or not. Unfortunately I
made no observations with the compound prism, (which seemed
to give just the right amount of dispersion), just before the time
of a principal minimum.

There is no difficulty in identifying the strong lines which I ob-
served in the green with the strong lines measured by Belopolsky
and printed in his table with heavy-faced type. F is the reference
line in both measurements, λ 4922.7 $= g$, λ 5014.3 $= f$, λ 5170.3
$= e$. There is, however, no line in his table corresponding to d,
the nearest line there given which seems to answer the descrip-
tion being at λ 5703.3, while my measurements gave for d, $\lambda =$
5670. Although these measurements were made with low dis-
persion, the independent results were in fair agreement, and I do
not think the errors of observation were great enough to ac-
count for a discrepancy of 67 tenth-metres. The finer lines pho-
tographed by Belopolsky were not visible with my apparatus.

The observations which I have recorded of the strong lines seen
in the green part of the spectrum after a principal minimum are
also in agreement with Professor Pickering's description of the
photographed lines above F, both as to the appearance of the
bright and dark lines and the direction of the relative displace-
ment.

Some of the phenomena presented by the spectrum of β Lyræ
are of particular interest. Is the dark line which appears above
D_3 at the time of a principal minimum, when dark lines are seen
in corresponding positions near other bright lines, a reversal of
D_3? We may safely assume such a relationship in the other
cases, but in the case of D_3 so strong an absorption would be
quite unprecedented. The line is narrow, while D_3 is broad; but
it is remarkable that on Nov. 14, when accurate measures were
made, this dark line was more nearly in the normal position of
D_3, with reference to the dark D lines, than was the bright D_3
line itself. The latter was relatively displaced toward the red,
by an amount nearly equal to the displacement of the other
bright lines.

It is also remarkable that the dark and bright lines should ex-
hibit a strong relative displacement at (or at least very shortly
after) the time of a principal minimum. Hence a simple eclipse
of one body by another would seem to be an insufficient explana-
tion of the diminution of light at this time, whatever constitu-

tion may be assigned to the two bodies. Evidently more obser-
vations are needed at this critical period. With the materials at
hand it is futile to attempt a complete explanation of the com-
plex phenomena presented by this star. It seems to me that
none of Professor Pickering's suggestions are likely to prove suf-
ficient. Photography promises to be the method by which the
solution will be reached, but I have given these visual observa-
tions in the hope that they also will be useful.

With regard to the two figures representing the appearance of
the D_3 line, I wish to say that although drawn to the same scale,
the originals were made under very different conditions. No. 1 is
from a sketch accompanied by micrometer measures with the
compound prism and large spectroscope, No. 2 is from a sketch
made with the small spectroscope which was used in most of the
observations, the spacing and widths of the lines being merely
eye-estimates.

NOTE ON THE SPECTRUM OF P CYGNI.*

JAMES E. KEELER.

In looking over my note-books for observations of β Lyræ, I
find the following notes in regard to the spectrum of P Cygni.
They contain some facts hitherto unpublished.

June 21, 1889. The spectrum is remarkably like that of β
Lyræ, but the hydrogen lines are sharper and more brilliant, and
Hγ in P Cygni is seen nearly as well as F in β Lyræ. The D_3 line
is thinner and sharper. The dark D line is present, but it is not
nearly so conspicuous as in the other star. A sharp fine line is
seen in the estimated position of f, but it is much brighter than f
in β Lyræ. On the other hand the line above D_3 (d), is not cer-
tainly seen. Compared with β Lyræ, the continuous spectrum
is dim.

July 11, 1889. The spectrum is the same as before. D_3 is
bright, and exceedingly fine and sharp;—much finer than in β
Lyræ. The dark D line is relatively fainter; f much brighter,
and about equal to d in β Lyræ. No line can be seen at the plac e
of d.

The above observations were made with the small spectro-
scope described in the previous article. The star was frequently
observed with the same instrument, without further results, and

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* Communicated by the author.

no changes were ever detected. Some measures were made on the night of Nov. 14, with the large spectroscope and compound prism.

Nov. 14, 1889. Two bright lines are seen in the green below *F*. Their positions were measured with the micrometer, with the following results:

$$
\begin{array}{ll}
F & \lambda\ 4861.7\ \text{(Assumed).} \\
g & \quad\ 4923.6 \\
f & \quad\ 5017.6
\end{array}
$$

These are evidently the same lines as those seen in the spectrum of β Lyræ. Their appearance is also the same; each is bordered by a dark line just above. The settings are on the bright lines.

D_3, as seen with this much greater dispersion, is sharper and narrower than the D_3 line of β Lyræ. The D lines could not be seen, but I thought there was a dark line just above D_3 and equal to it in width. No other lines were noticed.

These observations are given chiefly on account of the appearance of the bright lines in the green, which are described as having dark borders on their more refrangible edges, like the lines in β Lyræ after a principal minimum. It is not likely that this star also is a revolving system, and possibly some other explanation of the appearance is required in both cases. As only one observation of P Cygni was made with suitable apparatus, the appearance may have been merely a mistaken impression. Perhaps, in this star, the lines in the green, like those of hydrogen, are superposed on broad lines of absorption, the lower parts of which were less conspicuous than the upper, and for this or some other reason were overlooked. The star is beyond the reach of my present instruments.

ASTRO-PHYSICAL NOTES.

A New Method of Observing the Solar Corona without an Eclipse.—*To the Editor of Astro-Physics:* DEAR SIR: Your exceedingly interesting article "*On the Photography of the Solar Corona without an Eclipse*" encourages me in the belief that you and the readers of your esteemed journal may perhaps be interested in a method which I designed for the purpose of observing the distribution of the intense sources of ultra-violet light over the Sun's disc, and also of observing the solar corona without an eclipse.

The idea which led me to the design of this method rests on the hypothesis that the uppermost layers of the solar atmosphere and also the solar corona are rich in ultra-violet light of very short wave-length,—a characteristic of the luminescence of gases especially when it is produced by electrical discharges. Just a remark or two on this point before I proceed to the description of my method. In my investigation "*On Coronoidal Discharges*" (ASTRONOMY AND ASTROPHYSICS, June, 1892) I have referred to the possibility of the coronal streamers being due to electrical discharges in the solar atmosphere. I have since expressed my opinion on this point somewhat more strongly in a paper read before the New York Academy of Sciences on December 5th, 1892. In this paper I discussed the scientific value of the hypothesis which ascribes the coronal glow to oscillatory electrical flow in the extremely rarefied gaseous matter of the coronal regions, this oscillatory flow being due to the propagation of electrical waves from the Sun to the interplanetary space. The electrical waves again being due to disruptive discharges and other kinds of electrical disturbances in the solar atmosphere and on the solar surface. I have also referred to the possibility of the coronal glow being due to a fluorescence of the gases in the coronal regions, this fluorescence being due to the action of ultra-violet light of extremely short wavelength which radiates from the uppermost layers of the solar atmosphere, where, according to the above hypothesis, electrical discharges of more or less oscillatory character are going on continually. You can therefore see why I should have been anxious to devise some method by means of which I should be able to look at the ultra-violet light of the solar atmosphere and the solar corona.

The first method that I thought of was very similar to yours. I discussed it thoroughly with Professor Rees of Columbia College, and consulted also our mutual friend, Dr. Ames of Johns Hopkins, on some points concerning this matter; but the method seemed to offer difficulties which appeared to be beyond the skill of a man inexperienced in astronomical and astro-physical work, and I therefore abandoned it.

The second method consists in forming an image of the Sun and the surrounding region of the Sun on a very thin well ground plate of uranium glass or some other transparent fluorescent substance, and observing it by means of a fluoroscope. Fig. 1 gives the front view of the apparatus and fig. 2 gives a vertical section through the axis of the shaft.

Two well rolled flat thin steel plates e, f (fig. 2), 2 feet in diameter are to be held in position by three thick plates e, m, n, and rigidly connected to a shaft AB which runs in self-oiling bearings op. The plates having been fixed upon the shaft are to be enclosed in a cast-iron frame, gh, which is bolted to the base by bolts, ik (fig. 1). The thin steel plates are to have each 24 circular holes of 1 inch diameter arranged as indicated in fig. 1, the holes belonging to one plate being marked by Arabic and those belonging to the other plate by Roman numbers.

Fig. 1.
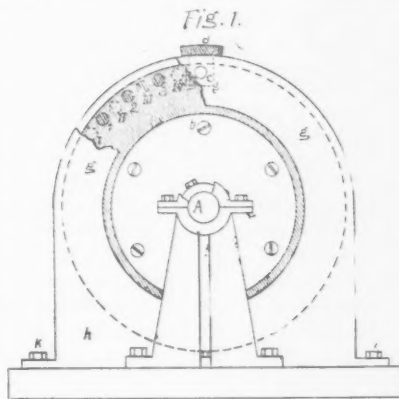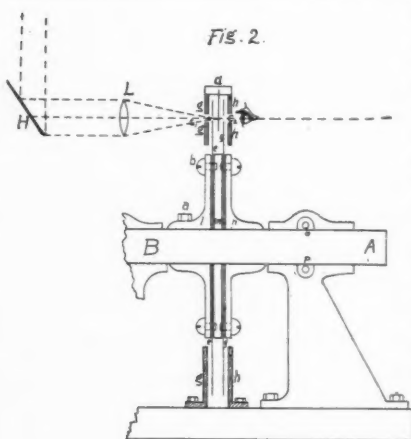
Fig. 2.

Resting on the frame at its highest point is a block d which carries the fluorescent plate, df (fig. 2). The frame has two circular holes, c_1 and c_2 (fig. 2), of the same dimensions as the holes in the revolving steel plates. The uranium plate is midway between these plates. A heliostat H with a speculum metal mirror and a quartz lens (or what is better still a speculum metal reflector) are used to form the image of the Sun or of the region surrounding the Sun (in which case a reflector or quartz refractor of short focal length is used) upon the fluorescent plate. An eye situated as indicated in fig. 2 should see the image by means of the fluorescent light.

To photograph the image it would probably be desirable to use some other substance instead of uranium glass. The angular velocity of the steel discs can easily be raised to such a value as to enable the observer to observe the fluorescent image during every $\frac{1}{2500}$ part of a second after each exposure of the uranium plate to the action of the solar light. Each exposure lasts the same fraction of a second.

The diffuse light of the sky would probably be eliminated in this way, especially if transparent fluorescent plates are used which are especially sensitive to ultra-violet light of very short wave-length. Should you think that the method deserves any serious consideration, please offer some suggestions which I would value very much and observe very carefully in the final design of the apparatus.

Very truly yours,　　　　M. I. PUPIN.

Columbia College, March 10th, 1893.

Dr. Pupin's ingenious method of observing the corona without an eclipse is a new way of applying a supposition common to many methods devised for the same purpose, *i. e.*, that the ultra-violet portion of the corona spectrum is stronger than the less refrangible region. If this supposition be well founded—and there are many reasons to think that it is—it would seem that Dr. Pupin's apparatus might succeed in rendering the corona visible to the eye. The experiments would be much more likely to result successfully if tried at a high altitude. Instead of a heliostat and quartz lens it would perhaps be advantageous to form the image of the Sun with a concave mirror of speculum metal, the whole apparatus being carried on an equatorial mounting. It would also seem desirable to cut off the direct light of the Sun by means of a metallic disc.

Photography of the Solar Corona without an Eclipse.—In a paper with the above title published in the March number of ASTRONOMY AND ASTRO-PHYSICS I have described a method of photographing the solar corona without an eclipse, with the spectroheliograph. It has occurred to me that the chances of securing the corona would be greatly increased by setting on the second slit of the spectroheliograph one of the dark lines in the blue or violet part of the mixed spectrum

of the corona and the sky. The bright continuous spectrum of the corona would be of its normal intensity at this point, while the disturbing light of the atmosphere would be reduced to the brightness of the dark line. The K line would probably prove most serviceable. The resulting advantage would be the protection afforded by the broad dark absorption band, and the additive effect of the bright K line in the corona.

March 16, 1893. ———————— GEORGE E. HALE.

The Large Prominence of Oct. 3, 1892.—On referring to my notes made on the above date I find this prominence was well seen here at from 7ʰ 20ᵐ to 8ʰ 50ᵐ A. M., G M. T., or about 5 hours earlier than the time when it was drawn by Herr Fényi at Kalocsa. When observed by me the prominence consisted of a compact mass of very beautiful interlacing filaments extending without a break from latitude — 22° to — 39° and about 100″ in height; there was a bright spot or "condensation" at — 39° and another at — 43° and outlying prominences were seen at — 15° and — 50°. The next morning at the same hour-hardly a trace of the prominence remained and there is little doubt that it must have been annihilated during the 24 hours as the Sun's rotation would not carry so large a form out of sight in this time. Herr Fényi's drawing seems indeed to show the prominence in the act of being blown to shreds.

Two other prominences comparable with the above in magnitude have been seen here during 1892, both being in S. latitudes. The first on May 14th, 3ʰ 40ᵐ P. M., extended for no less than 33° on the S.W. limb from latitude — 35° to — 68°, the highest parts being about 140″ above the limb. The other on July 19th on the S.E. limb appeared as a huge column of intertwining filaments, the base being at latitude — 40° and the highest parts nearly 3′ above a point on the limb at — 28°. Like the October prominence both these gigantic forms seem to have been very short lived. ———————— J. EVERSHED, JR.

Kenley, Surrey, England. ————————

Herr Schumann's Investigations on the Ultra-Violet Spectrum.—In his paper on "The Hydrogen line Hβ in the Spectrum of Nova Aurigæ and in the Spectrum of Vacuum Tubes (ASTRONOMY AND ASTRO-PHYSICS, February, 1893), Herr Schumann has pointed out some remarkable cases of reversals which are worthy of careful consideration in the interpretation of celestial phenomena. In a letter of more recent date attention is called in the following words to another point of interest in the same connection: "Among the lines not belonging to, but almost invariably present in photographs of the hydrogen-tube spectrum in addition to those of mercury, the cyanogen band at λ 3883 is especially noticeable. This band pertinaciously resists every attempt to free the spectrum of it. It is only after long heating and the passage of strong discharges through the tube that it begins to weaken in intensity. If, however, this band is taken together with the spectrum of hydrogen one finds that under certain circumstances it is very strong, and that it almost entirely disappears under certain experimental changes, but invariably reappears as soon as the former conditions are restored. I find that the cyanogen band always disappears when the temperature of the discharge is sufficiently increased. If, for instance, only one Leyden jar is used in the induction coil circuit, the band retains its full strength. But, if a second condenser of sufficient capacity is added, not a trace of the band remains. The mercury vapor from the air-pump acts in nearly the same way."

In the paper published in our February number and referred to above the first line on p. 164 should read: "at a pressure of 32mm. only the two lines Hβ Hγ are left." The subscripts were omitted in the author's manuscript, and had to be supplied from the context by the translator.

Differential Gravity Meters.—One by one those old landmarks known as "physical constants" are disappearing. Perhaps the latest step in this direction is the proposal of Mascart [*Comptes Rendus, 30th January, 1893*] to express our familiar "constant" *g* as a function not only of altitude and latitude, but also of time. Local variations in the direction of gravity (station errors) have long been known. At the Princeton Observatory, for instance, the geodetic latitude differs by some four seconds from the accurate determination of the astronomical latitude made by Professor McNeill. Time variations in the direction of gravity were predicted by Lord Kelvin many years ago, and are now being studied with great zeal.

Added to these we now have the observations of Mascart (*loc. cit.*) which led him to think that the *intensity* of gravity, at any fixed point on the Earth's surface, undergoes rather sudden minute changes.

These indications were obtained from a siphon barometer, the lower tube of which was filled with hydrogen and then sealed. Using a mercury column more than fourteen feet high, he detects any change in the weight of this mass by reading the change of level in the lower arm. The cross-sections of the columns are in the ratio proper to magnify the displacement in the hydrogen tube some twenty times.

Such an arrangement as this is, of course, keenly sensitive to any thermal change. To prevent sudden fluctuations it is placed underground.

The noteworthy feature of Mascart's record is that, aside from the slow, gentle changes corresponding to the temperature curve of the ground at that point, he finds sudden twitches or notches in the curve, assignable apparently to sudden changes in the intensity of gravity. These experiments are to be continued at the *Observatoire du Parc Saint-Maur*. The publication of curves showing the character and amount of these changes will be awaited with great interest.

It will be remembered that the differential gravity meter devised by Lord Kelvin and described by him at the Birmingham meeting of the British Association (1886) was abandoned not only on account of elastic "fatigue" in the flexed spring which he employed, but partly because Mr. Boys, then just out with his quartz fibres, proposed to use torsion in a horizontally stretched fibre, after the manner of a catapult whose arm is held back by gravity. It was hoped thus to obtain an instrument which would surpass Lord Kelvin's spring both in delicacy and precision. But if anything farther has come of Mr. Boys' torsion balance, it has escaped your reviewer.

It appears not unlikely that any of these methods possess sufficient delicacy; the *bete noire* of the whole problem being those vicious temperature variations which play havoc with so much physical experimentation. Lord Kelvin's spring, for instance, would detect a change in *g* as small as one part in two hundred thousand, yielding a clock error of a quarter of a second a day.

Meteorological Balloon.—M. Renard thinks he has obtained a cloth and varnish at once sufficiently light and impervious to hydrogen to make a balloon which will put below itself eleven-twelfths of the Earth's atmosphere, ascending to a height of 12 miles.

His proposition is to outfit such a balloon with a self-registering barometer, thermometer, and actinometer, and then set it free. The instruments are to be packed in a sort of interior skeleton of light willow work. The weight of the whole thing is only twenty pounds, and nearly half this is allotted to the meteorological apparatus. The estimated cost of each ascent is ten dollars. No mention is made of insurance. (*Journal de Physique*, Feb. 1893, pp. 63-67.)

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR MAY.

Mercury will be morning planet during May, rising about three quarters of an hour before the Sun during the first half of the month. During the last days Mercury will be approaching superior conjunction and therefore too near the Sun for observation. On May 20 at 1^h 06^m P. M., central time, Mercury will be in conjunction with Jupiter. The apparent distance between the two planets will be 56′.

Venus will be at superior conjunction on the morning of May 2 and will after that time be evening planet setting very soon after the Sun. Toward the last of the month one will be able to see the planet with the naked eye, by looking toward the sunset point between a quarter and a half hour after sunset.

Mars will be evening planet during May, setting a little after ten o'clock. His course will be eastward from the head of Taurus to the feet of Gemini. Mars will be in conjunction with the Moon, 3° 32′ south of the latter, May 18 at 4^h 15^m A. M.

Jupiter will be in conjunction with the Sun April 27 and will be too near the Sun for observation during the greater part of May.

Saturn will be in excellent position for observation during May, as it will be on the meridian in the early part of the night. One will find this planet in the constellation Virgo a little west of the third magnitude star γ. The planet is considerably brighter than any of the neighboring stars.

Saturn will be in conjunction with the Moon May 25 at 2^h 48^m A. M.

Uranus will be in its best position for observation for this year during May. This planet is in the western part of the constellation Libra, about two and one-half degrees west and one degree north of the bright star α Libræ. It is not visible to the naked eye but may easily be recognized, by its dull green disk, with a telescope of moderate power. Uranus will be in conjunction with the Moon May 27 at 5^h 44^m P. M. As seen from the center of the earth the planet will then be 1° 24′ north of the moon's center. As seen from observations in northern latitudes the parallax will throw the moon farther from the planet.

Neptune will be too low in the west in the early evening for observation during May.

MERCURY.

Date. 1893.		R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
May	5......	1 17.0	+ 4 53	3 59 A. M.	10 22.0 A. M.	4 45 P. M.
	15......	2 11.2	+ 10 37	3 51 "	10 36.7 "	5 21 "
	25......	3 21.2	+ 17 22	3 53 "	11 07.2 "	6 21 "

VENUS.

May	5......	2 56.2	+ 16 05	4 53 A. M.	12 00.8 P. M.	7 09 P. M.
	15......	3 45.9	+ 19 35	4 46 "	12 11.0 "	7 36 "
	25......	4 37.4	+ 22 12	4 46 "	12 23.3 "	8 00 "

MARS.

May	5......	5 36.7	+ 24 29	6 52 A. M.	2 41.1 P. M.	10 30 P. M.
	15......	6 05.9	+ 24 36	6 40 "	2 29.9 "	10 20 "
	25......	6 33.1	+ 24 25	6 30 "	2 18.6 "	10 07 "

JUPITER.

May	5......	2 29.7	+ 13 46	4 37 A. M.	11 36.0 A. M.	6 35 P. M.
	15......	2 39.0	+ 14 31	4 04 "	11 06.0 "	6 08 "
	25......	2 48.2	+ 15 13	3 31 "	10 35.8 "	5 40 "

SATURN.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
May 5......	12 29.5	− 0 18	3 31 P. M.	9 32.6 P. M.	3 34 A. M.
15......	12 27.8	− 0 09	2 50 "	8 51.6 "	2 53 "
25......	12 26.7	− 0 04	2 09 "	8 11.2 "	2 13 "

URANUS.

May 5......	14 24.7	− 13 52	6 21 P. M.	11 27.4 P. M.	4 34 A. M.
15......	14 23.1	− 13 44	5 40 "	10 46.5 "	3 53 "
25......	14 21.6	− 13 37	4 58 "	10 05.7 "	3 13 "

NEPTUNE.

May 5......	4 34.5	+ 20 30	6 10 A. M.	1 39.0 P. M.	9 08 P. M.
15......	4 36.0	+ 20 33	5 32 "	1 01.1 "	8 30 "
25......	4 37.6	+ 20 36	4 54 "	12 23.4 "	7 53 "

THE SUN.

May 5......	2 51.8	+ 16 28	4 45 A. M.	11 56.5 A. M.	7 08 P. M.
15......	3 30.9	+ 19 03	4 33 "	11 56.2 "	7 19 "
25......	4 10.9	+ 21 05	4 24 "	11 56.8 "	7 29 "

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A.................0^h 52^m 32^s
Decl.................+81° 17′
Period............$2d$ 11^h 50^m
1893.
May	3	5 A. M.
	8	5 A. M.
	13	5 A. M.
	18	4 A. M.
	23	4 A. M.
	28	4 A. M.

S. CANCRI.

R. A.................8^h 37^m 39^s
Decl.................+ 19° 26′
Period............$9d$ 11^h 38^m
May	7	1 A. M.
	25	1 A. M.

S ANTLIÆ.

R. A.................9^h 27^m 30^s
Decl.................−28° 09′
Period............ 7^h 47^m
May	1	11 P. M.
	2	11 "
	3	10 "
	4	10 "
	5	9 "
	6	8 "

S ANTLIÆ Cont.

	7	8 "
	8	7 "
	12	midn.
	13	11 P. M.
	14	11 "
	15	10 "
	16	9 "
	17	9 "
	18	8 "
	19	7 "
	24	midn.
	25	11 P. M.
	26	11 "
	27	10 "
	28	9 "
	29	9 "
	30	8 "
	31	7 "

δ LIBRÆ.

R. A.................14^h 55^m 06^s
Decl.................− 8° 05′
Period............$2d$ 7^h 51^m
May	2	midn.
	11	11 P. M.
	18	11 "
	25	11 "

U CORONÆ.

R. A.................15^h 13^m 43^s
Decl.................+ 32° 03′
Period............$2d$ 10^h 51^m
May	11	4 A. M.
	18	2 "
	24	midn.
	27	10 A. M.
	30	9 P. M.

U OPHIUCHI.

R. A.................17^h 10^m 56^s
Decl.................+ 1° 20′
Period............ $0d$ 20^h 8^m
May	4	3 A. M.
	4	11 P. M.
	9	4 A. M.
	9	midn.
	14	4 A. M.
	15	1 "
	20	1 "
	25	2 "
	25	10 P. M.
	30	3 A. M.
	30	11 P. M.

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magni-tude.	IMMERSION Washing-ton M. T. h m	Angle f'm N pt. °	EMERSION Washing-ton M. T. h m	Angle f'm N pt. °	Duration. h m
May 3	43 Ophiuchi.........	5.8	13 33	100	15 07	285	1 34
19	ω¹ Cancri...........	6.0	7 03	110	8 08	292	1 05
19	ω² Cancri...........	6.3	7 48	161	8 29	241	0 41
24	η Virginis.........	4.0	9 21	175	10 20	267	0 59

Phases and Aspects of the Moon.

		d	h m	
Apogee		May 2	midnight	
Last Quarter		" 8	8 24	P. M.
New Moon		" 15	4 47	"
Perigee		" 16	12 42	A. M.
First Quarter		" 22	8 52	"
Apogee		" 30	1 42	"
Full Moon		" 30	9 12	"

Configuration of Jupiter's Satellites at 8ʰ p. m. Central Time.*

May		May		May	
25	1 ○ 2 3 4	28	3 1 ○ 2 4	31	○ 1 4 2 3
26	♃ 2 3 ○ 4	29	2 ○ 3 1 4		
27	3 ○ 1 4 ●	30	2 1 ○ 3 4		

* The satellites of Jupiter are invisible before May 25th, Jupiter being too near the Sun.

COMET NOTES.

It is about time for some new comets to be discovered. The old ones are almost beyond the reach of even the great telescopes. Holmes' comet was, on March 11, so very faint that it was exceedingly difficult to obtain an accurate determination of its position with the 16-inch equatorial. It was about 1′ in diameter with very slight central condensation.

Brooks' comet 1893 I has vanished in the rays of the Sun. The following ephemeris by F. Ristenpart (*Astr. Nach.* 3154) shows that it may possibly be again picked up after it comes out of the solar rays in June or July.

Ephemeris of Comet 1893, I (Brooks 1892, Nov. 19)

	R. A.	Decl.	log r	log Δ	Br.
	h m: s	° ′			
Apr. 6	1 08 44	+ 16 51.0	0.2569	0.4447	0.225
22	18 26	15 26.4	2964	4694	167
May 8	26 58	14 05.3	3333	4830	132
24	32 48	12 42.9	3677	4839	113
June 9	35 35	11 03.9	3997	4749	101
25	34 23	8 55.8	4293	4580	096
July 11	1 28 06	+ 6 05.4	0.4569	0.4353	0.093

New Elements of Comet 1892 III (Holmes)—Mr. J. R. Hind gives the following elements in Astr. Nach 3152. They depend on observations Nov. 9, Dec. 7 and Jan. 5.

Epoch 1892 Nov. 9.5 Greenwich M. T.

$$M = 21° 12′ 43″.5$$
$$\pi = 346\ 16\ 04\ .7$$
$$\Omega = 331\ 35\ 38\ .2 \Big\} 1892.0$$
$$i = 20\ 46\ 46\ .4$$
$$\varphi = 24\ 06\ 16\ .1$$
$$\mu = 513″.90765$$
$$\log a = 0.5594143$$

Period = 2521.85 days.
Perihelion = 1892 June 13.9062

Middle Place (C − O)
$\Delta\lambda \cos \beta = -1″.1$; $\Delta\beta = -0″.4$

Ephemeris of Holmes' Comet 1892 III.—Although this comet has again almost vanished from sight we think it well to give the following ephemeris, that observers may keep watch for another possible outburst of light. The ephemeris is by M. Schulhof and is taken from *Astr. Nach.* 3153.

Paris Midn.	R. A.			Decl.			log Δ	Aberr. Time.	
	h	m	s	°	′	″		m	s
April 5	3	31	51.1	+ 36	22	58	0.55255	29	37
6		33	42.0		25	33			
7		35	32.0		28	06			
8		37	24.2		30	38			
9		39	15.5		33	08	55877	30	02
10		41	06.9		35	37			
11		42	58.5		38	04			
12		44	50.2		40	29			
13		46	41.9		42	53	56473	30	27
14		48	33.8		45	14			
15		50	25.8		47	34			
16		52	17.9		49	52			
17		54	10.0		52	09	57044	30	51
18		56	02.3		54	23			
19		57	54.6		56	35			
20	3	59	47.0	36	58	45			
21	4	01	39.4	37	00	52	0.57588	31	15
22		03	31.9		02	58			
23	4	05	24.4	+ 37	05	02			

Suggested Origin of Comet Holmes.—Mr. Corrigan's hypothesis being in the present state of our knowledge not susceptible of proof, yet must be allowed to have a look of probability about it in so far that if such collision betwixt two asteroids took place it might result in analogous phenomena to those we have been observing of late.

But I think the appearance of the comet at the time of discovery and for a few days after was not such as we should expect to result from a collision betwixt two bodies violent enough to cause both to fly into vapor.

When discovered it was accurately round with a bright circular nucleus reminding me much of H37⁴ on a larger scale. It was then 5′ in diameter and it retained this neat, well defined, circular appearance until the 9th of Nov., although it increased in diameter to 5′ 42″.

This neat, sharp, distinct circularity appears to me incompatible with the results of a collision. I should say the material of the two bodies would fly out at right angles to the line of impact and as this line would not be directed in the line of sight we should never see the expanding mass as a circle nor do I see how to account for so distinct an outline.

Again the result of a collision violent enough to produce such an expansion would be considerable heat and light and I am not aware that this comet has ever done more than feebly reflect sunlight without ever emitting the smallest light of its own. Of course the masses of the asteroids being very small they would not collide with the violence of larger masses but if we postulate sufficient force of impact to reduce to fluidity even we ought to get considerable light.

But I think there is the previous question of whether any collision is possible betwixt two bodies of commensurable mass while they are submitted to the controlling influence of the Sun. If they were approaching each other directly, such collision might be possible but if travelling in the same direction round the Sun even in the same orbit, the result of their mutual attractions would be to retard one and accelerate the other; closing in one orbit and widening the other so that they would pass without collision and ever after revolve round their

common centre of gravity as a double asteroid. If approaching a node common to both in converging lines they would also be compelled to commence the same revolution because of their differences of speed producing the same accelerations and retardations. Of course these considerations do not apply to bodies of great differences of mass or when not subjected to the influence of a third more powerful influential mass such as the Sun furnishes, in case of the solar system.

I think we must reject Mr. Corrigan's ingenious hypothesis.

<div align="right">EDWIN HOLMES.</div>

After closing letter it struck me that the result of such a collision would be to leave no nucleus at all. If it was heavy enough to drive it into vapor this vaporization would occur in a very short time and not as in the case of the comet occupying a week or more. Perhaps half an hour would suffice to raise the two masses to the intensest heat. <div align="right">E. H.</div>

Mr. Denning's Drawings of Holmes' Comet.—Mr. W. F. Denning sends the following note to accompany the drawings which are reproduced in our Frontistispiece:

In response to your request for drawings of Holmes' comet, I send 3 pencil representations which will exhibit the marvellous alteration of structure which occurred between November 9 and 19.

On Nov. 9 I saw the comet as a perfectly round mass of nebulosity with a bright central condensation. The edges of the comet were very definite against the dark sky and in this respect the object might compare with a planetary disc Its diameter was 5' 40".

On Nov. 16 it seemed to have been transformed into an entirely different object. The diameter had increased to 10' 33" and the appearance was that of cometary head devoid of tail. The nucleus was knotted and in the form of a streak of bright material running through the central part of the comet. There was a small star just N. of the W. extremity of the nucleus. The comet was much fainter than on Nov. 9.

On Nov. 19 a further expansion had occurred and I found the mean diameter about 14' 30". The comet was now a pear-shaped mass of faint nebulosity. It had developed a short tail but was much fainter generally than on Nov. 16.

The last time I saw the comet was on Feb. 12, 1893. I also examined it on Feb. 11 when the sky was better and found the object still fairly conspicuous. The brighter portion of the head consisted of knots of nebulosity and the comet could easily have been mistaken for a very faint star cluster. A feeble tail was directed from the head towards N. E. and nearly in the direction of the bright star of β Trianguli which was in the same field with the comet. W. F. DENNING.

Bishopston, Bristol, February, 15, 1893.

Definitive Elements of Comet 1890, III.—In *Astr. Nach.* 3151 is given a determination of the elements of this comet from all the available observations. The comet was observed only from July 19 to Aug. 6 so that the observations number only 41. They are represented as closely as could be desired by a parabola.

$$T = 1890 \text{ July } 8.577276 \text{ Berlin M. T.}$$
$$\pi = 99° \ 58' \ 02''.24$$
$$\omega = 85 \quad 39 \quad 36 \ .86 \Big\} \ 1890.0$$
$$\Omega = 14 \quad 18 \quad 25 \ .38$$
$$i = 63 \quad 20 \quad 03 \ .70$$
$$\log q = 9.8831669$$

Search Ephemeris for Finlay's Periodic Comet, 1886 VII.—The only periodic comet due this year is that discovered by Finlay in 1886, the elements of which bore a close resemblance to those of the lost comet of DeVico. Mr. L. Schulhof has published a search ephemeris, part of which we give below, for it in *Astr. Nach.* 3154. The uncertainty of the perihelion passage is hardly more than ± 2 days. This will correspond on May 1, to an error of ± 5^m in R. A. and ± 30′ in Decl. The comet will not be favorably situated for observation in northern latitudes until the latter part of May, when it may be observed in the morning.

Paris Midn.	R. A.			Decl.		log $\varDelta$	Br.
	h	m	s	°	′		
April 6	21	06	36	− 18	42.9	0.2596	0.112
7		09	45	18	30.6		
8		12	55	. 18	18.0		
9		16	07	18	05.1		
10		19	20	17	51.9	0.2445	0.126
11		22	34	17	38.4		
12		25	49	17	24.5		
13		29	06	17	10.3		
14		32	25	16	55.9	0.2294	0.141
15		35	44	16	41.2		
16		39	05	16	26.1		
17		42	28	16	10.7		
18		45	52	15	54.9	0.2142	0.159
19		49	17	15	38.8		
20		52	44	15	22.4		
21		56	12	15	05.6		
22	21	59	41	14	48.5	0.1992	0.179
23	22	03	12	14	31.0		
24		06	45	14	13.2		
25		10	19	13	55.0		
26		13	55	13	36.5	0.1844	0.202
27		17	32	13	17.6		
28		21	11	12	58.3		
29		24	51	12	38.7		
30		28	33	12	18.7	0.1699	0.227
May 1		32	17	11	58.3		
2		36	02	11	37.6		
3		39	49	11	16.5		
4		43	37	10	55.1	0.1559	0.255
5		47	27	10	33.3		
6		51	19	10	11.1		
7		55	12	9	48.5		
8	22	59	07	9	25.6	0.1424	0.286
9	23	03	04	9	02.3		
10		07	02	8	38.6		
11		11	02	8	14.6		
12		15	03	7	50.3	0.1297	0.319
13		19	06	7	25.6		
14		23	11	7	00.6		
15	23	27	17	′ − 6	35.3		

New Asteroids.—Three new asteroids have been discovered since our last note The one announced in February as 1893 H turned out to be 1893 G and was on the same plate with (42) Isis.

1893	―Photograph―				―――First Observation――――			
	By	At	Date	Mag.	Gr. M. T.	R. A.	Decl.	
					h m	h m s	° ′ ″	
F	Wolf	Heidelberg	Jan. 16	13.0	Jan. 16 12 47	9 22 04.2	+ 19 49 46	
G	Charlois	Nice	Jan. 21	11.5	Jan. 22 16 13	9 31 33.3	+ 25 13 22	
J	Charlois	Nice	Feb. 11	12.5	Feb. 15 6 48	10 19 28	+ 15 02	

The Total Solar Eclipse, April 15-16, 1893.—By the time the most distant of our readers have received this number of A. AND A.-P., the total eclipse will probably have been witnessed by the several parties which have gone to South America and Africa to observe it. This eclipse being the last in the present century which is likely to add to our knowledge of solar physics, preparations have been made to utilize the few precious moments of totality to the best advantage possible under the circumstances. At least six important expeditions will observe the eclipse, two in Chili, two and probably more in Brazil, and two in Africa.
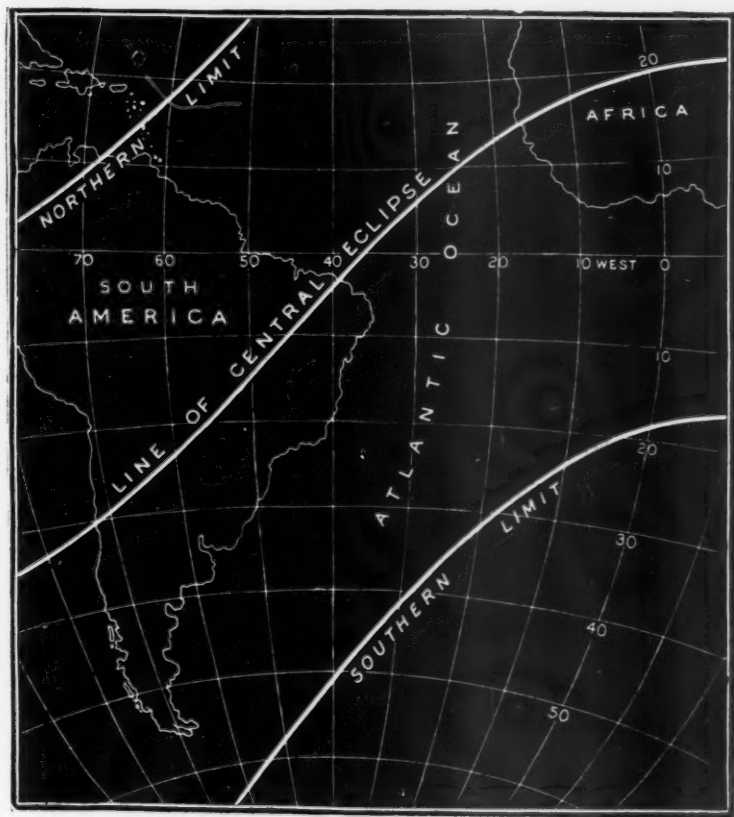
FIG. 1.

A glance at the accompanying chart, Fig. 1, will give a general idea of the location of the line of central eclipse. The shadow of the moon first touches the earth in the Southern Pacific Ocean, and passing to the northeast strikes the coast of Chili, crosses Brazil and the Atlantic Ocean, entering Africa just north of the mouth of the river Gambia, and leaves the Earth in the Sahara. The width of the path of the total eclipse is about three times the width of the line drawn on the chart.

Fig. 2 shows on a larger scale the points on the African coast from which the total phase of the eclipse may be seen. From *Nature*, Feb. 2, 1893 we learn that an English expedition will be located in Fundium (a station not shown on the map) on the River Salum, 60 miles from Bathurst. This expedition will consist of Professor T. E. Thorpe, Mr. A. Fowler, Mr. Gray, and Sergeant J. Kearney, R. E. They will endeavor to obtain photometric measures of the intensity of the corona with the equatorial photometer, the integrating photometer and bar photometer; spectroscopic observations with the integrating, radial and tangential slit spectroscopes; and photographs of the corona with Abney and Dallmeyer coronographs.

A French expedition under MM. Deslandres and Bigourdan has been sent by the Bureau des Longitudes of Paris to Joal, Africa. M. de la Baume Pluvinel will also go to Joal to photograph the corona.

In Brazil an English expedition under Mr. A. Taylor will be located at Para Curu, on the coast about forty miles west of Ceara. They will obtain photographs of the corona and spectroscopic observations with instruments exactly similar to those used in Africa. In the same vicinity there will also probably be a French party, and a Brazilian party under Mr. Cruls. An expedition from Cordoba, Argentine Republic, under Mr. Thome will probably observe the eclipse near Rosario de la Frontera, Arg. Rep.

In Chili there will be two parties, one from Harvard College Observatory under Mr. Bailey, and one from the Lick Observatory. Just where these parties will be located is not known. Fig. 3 gives a map of the region of totality near the Pacific coast, showing the readily accessible points. We understand that Professor Schaeberle, who goes alone, depending upon finding local assistants, intends to go beyond the terminus of the railroad and find a station among the mining camps in the mountains. He carries with him a 6½-inch equatorial and a 40-foot photoheliograph of 5 inches aperture, and will attempt to photograph the inner and outer corona.

The United States government has made no appropriation for eclipse observations. Mr. D. P. Todd writes that he has had to give up his cherished hope of observing the eclipse. The same is probably true of Mr. H. S. Pritchett, although we have not heard from him directly.

Meteor.—Last evening, at 8.33, a quite bright meteor fell in the N. W. in the constellation of Andromeda. The general direction was S. E. passing near γ Andromedæ. It was accompanied by a bright train, although both path and train were not long.   EARNEST BUTTRICK.

100 Wilder St., Lowell, Mass., March 13, 1893.

"**Shaking the Foundations of Science.**"—In an editorial under this title, *Nature* (Jan. 5, 1893), enters a vigorous protest against the proposed construction of an underground railway close to the College of Science buildings at South Kensington. With trains running at short intervals on such a railway, accurate measurements of any kind would be quite impossible. A similar project was entertained two years ago, but it was finally abandoned. The danger is one to which institutions in great cities are always exposed. In this case we hope that the interests of the college will be respected, or that some other route for the railway will be found to offer superior advantages.

FIGURE 2

MAP
OF PART OF THE DESERT OF ATACAMA
CHILE
SHEWING ZONE OF TOTALITY OF SOLAR ECLIPSE
OF 16ᵗʰ APRIL 1893
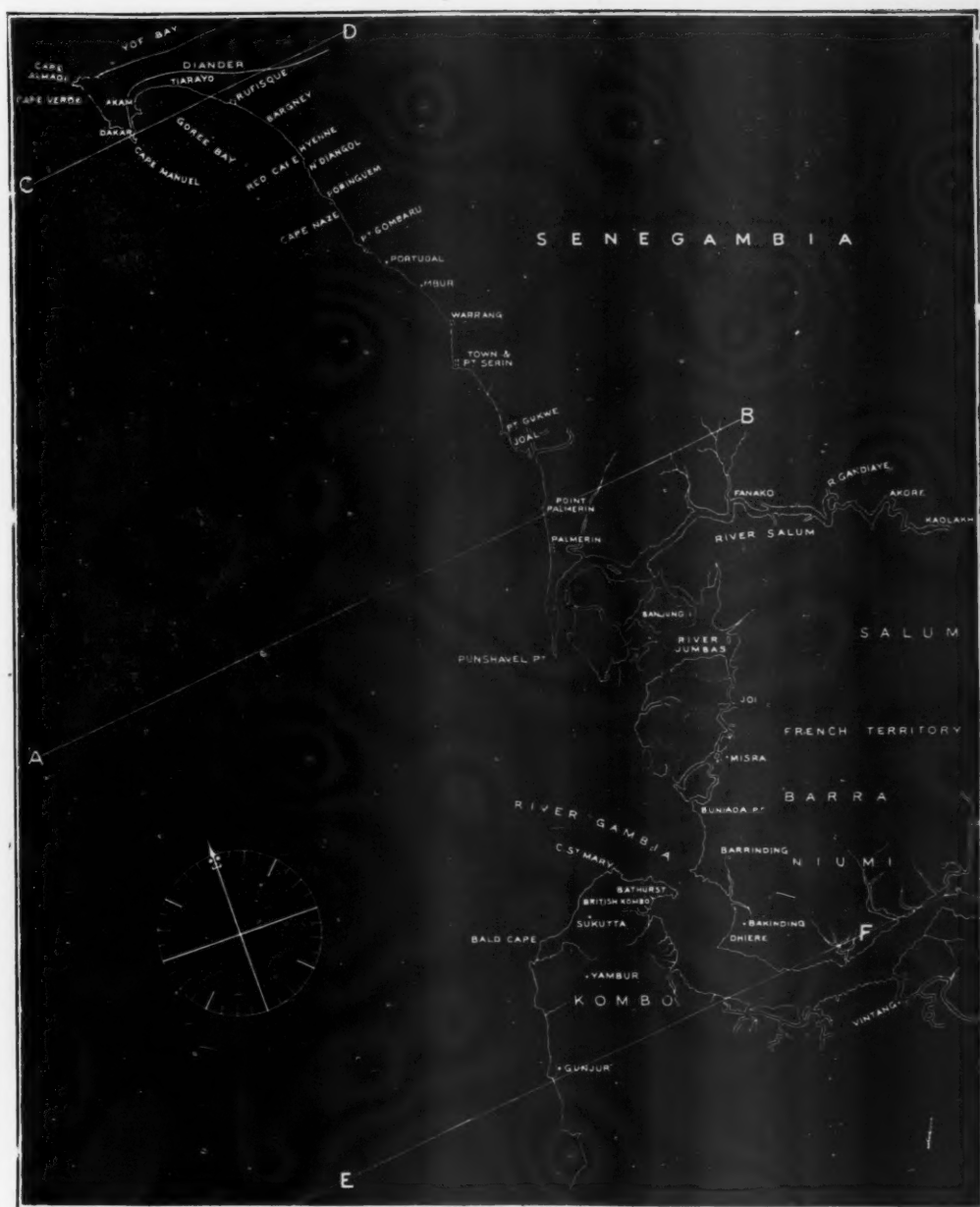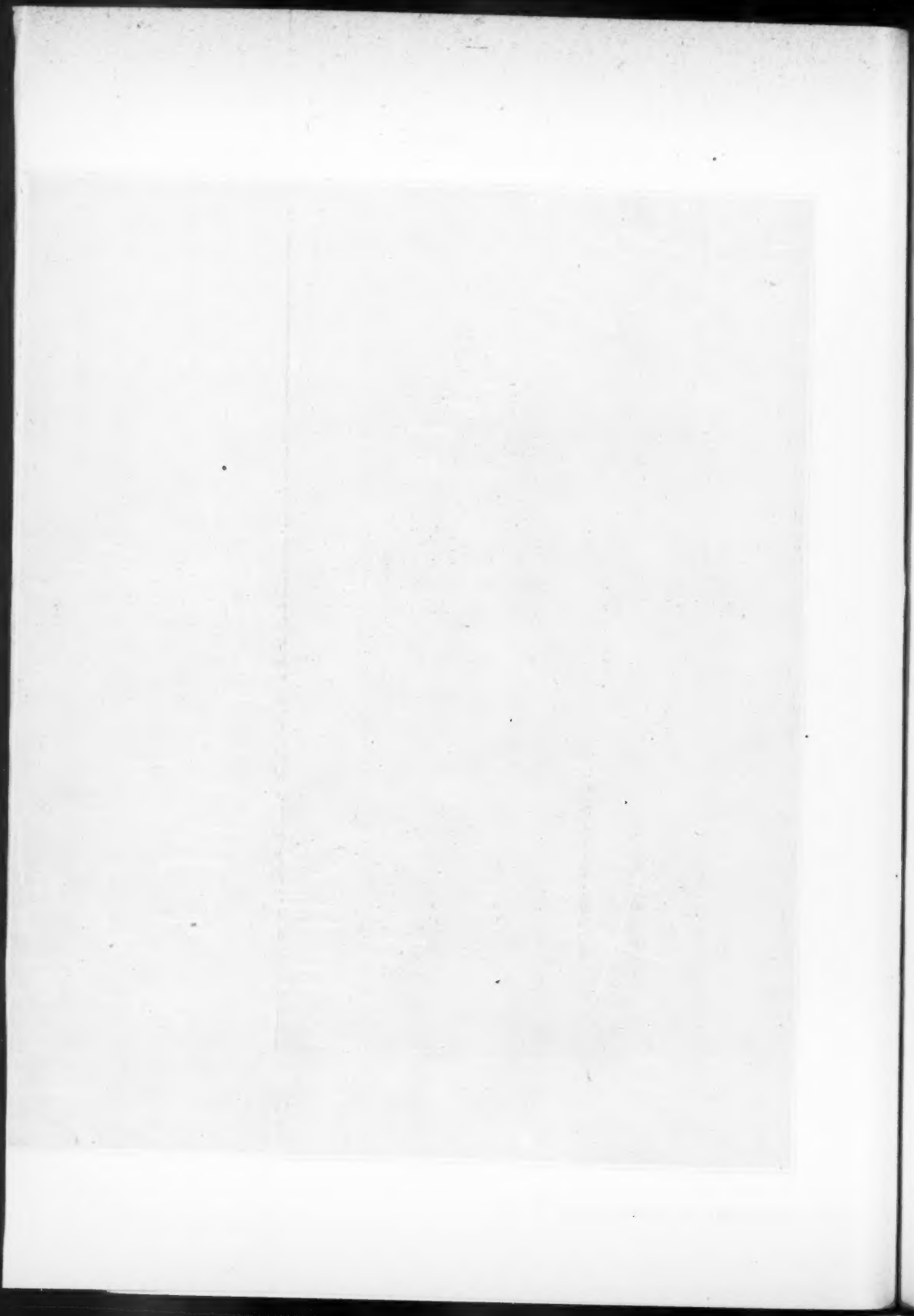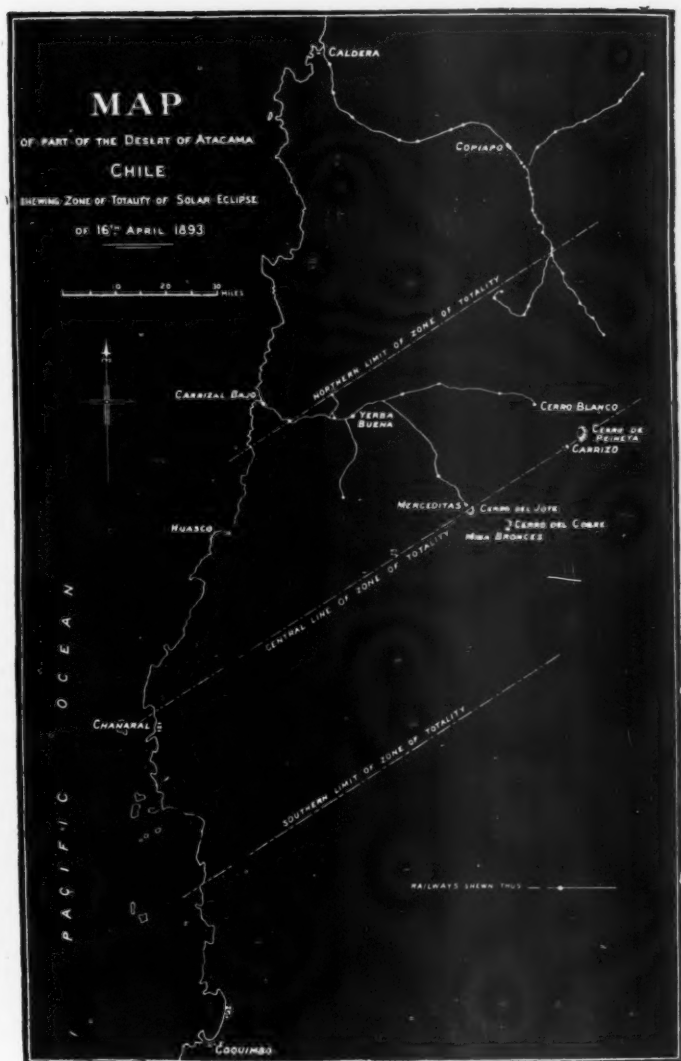
FIG 3.

NEWS AND NOTES.

Popular Astronomy.—There is little doubt but that the demand for popular instruction in astronomy is increasing constantly. This is seen in the attitude of teachers of this branch in secondary schools; in the rapidly growing numbers of students and amateur astronomers, in the multiplication of small telescopes, and in the general popular interest in astronomy everywhere. Those who conduct this journal have been profoundly impressed with this fact for some time in the past, but have seen no definite way in which to meet wisely and effectively this most rational demand of those who need and greatly desire the popular and student lore of astronomy. The oldest and broadest field of the sciences certainly has material enough to supply any such demand if it was a thousand fold larger. Every astronomer knows this. Every intelligent student believes it, and every earnest thinker and worker in science has a right to ask for common property in this noble heritage of astronomical knowledge that has come down to us from most ancient times.

Astronomy Popularized.—The main question then is how can astronomy be popularized so as to meet existing needs, and come within the range of self-instruction for those who care enough about it to do anything to gain the knowledge desired. It is evident, in the first place, that those who can instruct in this way, and are willing to do so, should be brought into closer relations with those who are to be instructed. This can be done most generally and effectively by a suitable monthly publication devoted to this kind of work. Such a publication should be issued ten times a year, continuously during the months that schools and colleges are in session and omitted during the months of July and August. Teachers and students would then be provided with courses of study and observation of objects that might be seen, on any clear night, by the naked eye, the opera-glass and the small telescope, at the time, while they are reading and thinking about them. What teacher or advanced student does not know that astronomy learned from books only is short-lived at best? It is all so easily forgotten, if it must be remembered chiefly, as a series of facts and pictures seen on the printed page. But if the student can see and picture for himself, in orderly way, the important things in astronomy that he is prepared to think upon, and which he can largely comprehend, who does not know that interest and enthusiasm would be aroused by such a natural method of study and work that could not be secured in any other way, except under the personal guidance of a competent instructor. It would be very easy to give instances of self-instruction in this same general way, only under less favorable circumstances. Some of our greatest astronomers of the present time have come to eminence by very rough ways. What has been done under a stress of unfavorable circumstances by a few, might be accomplished by many more, if judicious and timely aid were offered to direct willing energies for rapid progress.

Amateur Study of Astronomy.—Since we have understood the views of prominent educators from different parts of the United States, as learned from a discussion recently held in Chicago, on the requisites for admission to college in astronomy, we are the more interested in presenting some better plan to show the educating power of the elements of this science. Briefly stated it is this:

1. Study by topics with observation. The six topics chosen for the begin-

ning of study would be, the stars, Moon, planets, Sun, comets, and nebulæ, in this order, or any other when observation is most favorable, for they do not so depend on one another that confusion would arise if any order is pursued which would bring most aid by observation. The means of observation would be by naked eye, opera glass and the small telescope. There is abundant work for each and all these instruments. We will later speak of the details.

2. A monthly publication with the title *Popular Astronomy*, intended for students, teachers and amateurs and in no sense professional, except to be accurate in statement of fact, and principle without being technical in terms. It should contain at least 48 pages each month chiefly giving such matter as may be needed by the classes above named. Such a publication should be exactly what is needed to furnish a guide for self-instruction in the elements of astronomy to those for whom it is written. It should be a medium for queries and answers for methods of work, facts, books, and theories to supply individual wants. Its writers should be the best that can be procured for compensation. Its illustrations should be ample and thoroughly accurate. A full series of star maps should be furnished though the expense incurred would be heavy. The cost of starting such a publication would be at least $1,000, but the good work that it would begin and perpetuate can not be estimated in that way. We are ready to undertake this new publication provided one hundred teachers of astronomy, students and amateurs will unite with us and secure ten subscribers each at a uniform price of $2.50 per year. We can be ready to issue the first number for the month of September, 1893. Correspondence is solicited from every one interested in this new venture.

Lunar Photography.—In an article recently published in the *English Mechanic* upon double stars and other astronomical subjects by Mr. S. W. Burnham, he takes occasion to reply to some of the statements which have been made regarding the alleged discoveries on the lunar negatives made at Mt. Hamilton. We make the following extract:

"Referring to the Moon photographs taken at Mount Hamilton with a 36-inch refractor, alluded to by "F. R. A. S.," and the question of alleged discoveries in the positives of "rivers," which have been called in question by M. Prinz, of the Royal Observatory at Uccle, I would suggest the best way of determining whether these details really exist is to examine the lunar surface under the same illumination with any convenient telescope. A very moderate aperture will be sufficient for the purpose. All that is shown on these or any other photographs of the Moon, can be seen with instruments in the possession of most amateurs, and certainly many of them will show scores of details not found on the negatives. At present photographs of the Moon and planets, however large may be the aperture with which they were made, have only a pictorial value. They may be of some interest as showing general areas of the Moon, but cannot compete with other methods of delineating the details which are shown under favorable circumstances to the eye in apertures of 6-in. and upwards. The photographs of the Moon made with the Lick telescope, when compared with what can be seen with the eye with very much less optical power, are precisely the same as the photographs of Jupiter, Saturn, Mars, etc., when compared with what would be obvious to the eye with the same inferior instrument. To those who have made any photographic experiments in this line, or who have examined with any care the results obtained by others, independent of the claims made of their scientific value, this is too obvious to admit of argument.

Nothing whatever is gained by enlarging an original negative, aside from making a picture which requires a less close inspection. Nothing in the way of details can be shown in the enlargement which is not found in the original. Of course, it goes without saying that many details may be pointed out on these Moon negatives, and others taken with much smaller apertures, which are not shown in any drawings. Hundreds of minute markings could be noted by any skilled observer with a moderate telescope which he would be unable to find on any existing sketches, simply because no one has thought it worth while to reproduce them. These things are in no sense of the word *discoveries*, any more than a faint star shown on a long-exposed plate of the Milky Way is a discovery.

It may be mentioned here that the first series of Moon negatives with the Lick telescope, running through an entire lunation were made by me in 1888. Many of these have been reproduced in various publications since that time, and are familiar to most readers. Though not all of equal excellence, owing to the varied atmospheric conditions under which the exposures were made, many of them were as perfect as could be expected with such an instrument, and so far as I know, nothing better has been done since in the way of definition or otherwise. I have made an extensive use of these and other negatives made since that time for the reproduction of enlarged positives and negatives, lantern slides, etc., and the views given above as to the scientific value of such an application of photography are based upon this work and a careful study of the results.

The time may come when we can make a picture of the lunar surface, or of a planet, as we see it with the same aperture through an eye-piece magnifying three or four hundred diameters; but now this seems a long way off. At present photography no more supplants the observer of planetary and lunar surfaces than it takes the place of the double-star observer in the discovery and measurement of stellar systems.

Professor Barnard at Evanston.—"Astro-photography" was the subject of Professor Barnard's talk at the Evanston Club on the evening of the 15th of March. The audience was a large and appreciative one and the speaker was in his usual happy vein. Nothing aroused more genuine interest than the development of *Swift's Comet 1892*, as shown on the screen.

The power of the method and the skill of the photographer were also beautifully illustrated in the reproductions of the cloud forms of the Milky Way. The *Evanston Club* has a weakness for getting its information first-hand. They recognized in Professor Barnard's learning a soundness and freshness which combined to make it both attractive and adhesive.

Planning for Greater Telescopes.—It is with some surprise that we notice much in current scientific and popular journals of recent date about the manufacture and uses of telescopes very much larger than any now in existence. We did not give particular heed to the earlier notices of this favorable sentiment which began to grow over one year ago, for it then seemed as if but little would be likely to come of it. But later when such astronomers as Mr. Common, and Professor Pickering, and such manufacturers and opticians as Mantois, Clark and Brashear, and others that might be named, began to speak favorably of undertaking to construct telescopes of any size desired, it seemed that our science was taking on new life in a most important sense. Observers will have to stop and think a while and try to make up their minds whether or not the limit of size in the telescope has been reached in view of unsteady atmosphere and the nature of light, so that large increase of magnifying power may be used with possible or proba-

ble advantage. It now seems clear that refracting or reflecting telescopes much larger than any now in existence can be made, if those who ought to know have judged rightly, and it is probably true that money is ready to build the largest instrument that can be made, if those who would undertake it could be reasonably assured that the outlay would be of real service to astronomy in penetrating unknown fields of useful research. Now the real question seems to be, can much larger instruments be expected to do much more, or really any more, good work than those of the largest size already in use? If not, it would be very unwise to waste money in such fruitless attempts. But, on the other hand, if there is a reasonable hope of doing *some* more than possibly could be done with existing telescopes by the aid of still larger ones, by all means let us have them speedily. Astronomers experienced in the use of large instruments ought to be able to give useful evidence at this point of study of this important question. They are generally invited to do so through this publication.

Screens to Protect the Telescope from Wind Tremors.—Noticing in the *Astronomical Journal* that Professor Barnard had suggested a system of canvas curtains to cover part of the opening in the dome of the Lick Observatory to secure the great telescope from vibration on account of the direct pressure of the wind upon it, I have written him a note suggesting that a *twine netting with small meshes,*—say, one-half inch square, and made from heavy, strong twine,—may be made in the form of a long screen, large enough to fill the whole slide opening except that part through which the telescope may be pointed. The size of the mesh and the means of attachment and manipulation can be cheaply and easily determined by trial, but when once determined, a flexible wire netting may be substituted, although I should prefer the twine. The canvas will make much noise and the netting will be free from noise.

I have made this suggestion because I know from many years of experience that a high paling fence breaks up the direct force of the wind completely. I learned the trick long ago when using brush to protect my tents from heavy southeasters. I recommended it to Mr. Woodward, proprietor of the Woodward Gardens of San Francisco, and he completely protected the Gardens by an open fence that must now be thirty feet high. Visitors on the exposed Meiggs Wharf at San Francisco will remember what an unexpected protection the adoption of the eight foot paling fence on the windward side afforded them in the most violent summer winds tearing through the Golden Gate.

I am sure that in all these observations in which the telescope is vibrated by the direct force of the wind there will be found almost absolute quiet if the proper size of mesh is secured ; and that the temperature will be very slightly, if at all, changed.   GEORGE DAVIDSON.

A Note on the Draper Catalogue.—When writing my former articles I had not seen the introductory volume to the *Draper Catalogue* nor was I aware of its existence though it bears the date of 1891. There are two useful tables in it arising from the variances as to the spectra of certain stars between the *Draper Catalogue* and the observations of Vogel and Konkoly respectively. Professor Pickering had these spectra re-examined with photographs of longer exposure and the result is between 200 or 300 corrections. This result suggests a very large number of corrections if the entire catalogue had been re-examined. A considerable number of spectra classed as A became B in the revised version, but the very small proper motion of stars with this type of spectrum is borne out by the additions. The spectrum E often passes into G with longer exposure, and I think there is

no doubt that stars with this latter spectrum are referable to the Capellan not the Arcturian class. The corrections chiefly occur with the fainter stars and scarcely produce any effect on my analysis of Auwer's Catalogue (reversed by Herz and Strobl) which appears in ASTRONOMY AND ASTRO-PHYSICS for December 1892. The changes in the Pulkova Catalogue are somewhat greater. I have found some other errors in my analysis in this case and I think it would be improved by striking out all stars which appear also in the catalogue of Auwers so as to have two independent results. I propose therefore to forward an amended analysis of the Pulkova Catalogue when I have time to complete it.

I doubt the validity of Professor Pickering's conclusions as to the structure of the Galaxy. They seem to me to depend in a great measure on the selection of the stars in the *Draper Catalogue* which is not an impartial one as regards different parts of the sky. It omits northern stars brighter than the 5th magnitude and includes others not much brighter than the 8th. Statistics founded on such a catalogue are of very little value. We require either completeness or impartial selection to ground valid inferences on.   W. H. S. MONCK.

Removal of Warner Observatory from Rochester, N. Y.—Replying to your inquiry if the Warner Observatory is to be removed from Rochester, I answer, yes. Though the matter is yet unsettled owing to the prolonged absence in Europe of its founder, yet it may not be amiss to give the readers of your journal the reasons which lead to so extraordinary an event. Not to go too much into detail at this time, I will say they are three: (1) The erection of a large church with steeple and five heated chimneys adjoining the Observatory lot on the west has to a great extent destroyed the view in that direction. (2) The vast number of electric street lights entirely surrounding the Observatory, from a few rods to three miles distant, has so ruined the work of the discovery or observation of nebulæ that, practically, it has been abandoned. When the ground is covered with snow and the trees denuded of their leaves, the sky illumination almost equals that from a gibbous Moon. (3) The frequent and long continued cloudiness of the sky in this region, surpassing in this respect every place in the country save Vancouver, calls for its removal to a more propitious climate.

Where will be its future location is not yet decided, but, probably after Mr. Warner's return, one of the many sites offered will be personally inspected and chosen. Invitations have been received from Texas, New Mexico, Arizona, California, Colorado, Missouri, Iowa and Nebraska. My desire is to locate farther south, as between the equator and 38° of north latitude there lies a belt encircling the globe on which no large telescope has ever been used.   LEWIS SWIFT.

Warner Observatory, Rochester, N. Y.,
    March 12, 1893.

New Telescope for Drake University.—For the last two years Professor W. A. Crusenberry, of Drake University, Des Moines, Ia., has been pursuing the post-graduate course of study in mathematics and astronomy offered at Carleton College, spending a considerable portion of his summers at Goodsell Observatory in regular observing. His progress in practical astronomy has been rapid and most encouraging to himself, considering the fact that he has carried all his regular college duties at the University in the mean time. In view of his unusual efforts for better preparation for instruction and work in astronomy, the many friends of Drake University and Professor Crusenberry in particular, will be gratified to learn that General Drake, the founder of the University that bears his name, has given the means for the purchase of a new telescope which is to be or-

dered immediately. Professor Crusenberry is now in correspondence concerning the size of glass, kind of mounting and apparatus to go with it. When a good man is thoroughly ready to do good work the way will be opened for him.

Honors for E. E. Barnard.—It was an historical event for all concerned, when on March 8th, 1893, before a large audience at Vanderbilt University, Nashville, Tenn., Chancellor Garland, the venerable head of the university, conferred on E. E. Barnard of Lick Observatory, the degree of Doctor of Science, in behalf of the Faculty of that institution. It was a delightful surprise and was greeted by enthusiastic applause.

In delivering the diploma Dr. Garland told the story of Professor Barnard's life: First, an untutored boy, applying for a situation in a photograph gallery; then a youth of splendid efficiency in the art rooms, where he spent his days, while at night whenever the skies were clear he might be found on the roof of the gallery studying the stars through a small telescope; next, a young man at Vanderbilt University laboring by day in books of science and at night having free access to the university telescope; suddenly famous throughout the country as a discoverer of comets; then chosen to be one of the observers at the Lick Observatory, Mt. Hamilton, Cal., where stands the finest and largest telescope on earth, and now a man whose name will go down the ages beside that of Galileo because of his discovery of the fifth satellite of Jupiter.

On the following evening Dr. Barnard was royally banqueted by his many friends of Nashville.

The Structure of the Galaxy.—The list of the Galactic Longitudes and Latitudes of stars given by Mr. Marth in the *Monthly Notices* of the R. A. S., enabled me to test to a certain extent the theory that the Galaxy is a collection of Sirian stars, the solar stars being pretty uniformly distributed over the sky. The list only contains 180° of Galactic longitude but we are promised the remaining stars in a future number when I may be able to give you more definite results. The following is a rough analysis of the stars from the Harvard Photometry (not exceeding magnitude 6.0) comprised in Mr. Marth's list. For latitudes of more than 20° the list is evidently incomplete. (The Galactic longitudes are in all cases 0° to 180°).

Latitudes (Galactic)	Sirian	Capellan	Arcturian
0° to 5°	162	41	66
5 to 10	140	33	66
10 to 15	115	25	54
15 to 20	121	35	55
over 20	52	15	38

Considering the narrowing of the zones as we proceed to higher latitudes I think there is very little trace of condensation of any class of stars in the region of the Galaxy, nor do the proportions between the different classes of stars vary considerably during the first 20° of Galactic latitude on either side.

The type B is included as Sirian. The relative numbers of stars with this type under the 5 heads are 12, 10, 12, 11 and 3, thus showing no aggregation. The numbers for type M are 6, 7, 3, 7 and 5 respectively.   w. h. s. MONCK.

Dublin, March 1st, 1893.

Errata.—Page 211, line 29, read diameter for surface.

The last term of equation 6 above should be

$$2.5 \log \left(\frac{S}{S'}\right)^2 \text{ instead of } 2.5 \left(\frac{S}{S'}\right)^2.$$

Last line page 303, for Anniuare, read Annuaire.

Wolsingham Observatory.—The report for the year 1892 has been received. It shows that 116 new third type stars and one variable star have been found in zones $+ 55°$ and $56°$. In the autumn, the telescope was entirely devoted to the revision of double stars in connection with the forth coming edition of "Celestial Objects for Common Telescopes." Of this work Mr. Espin says:

It may be interesting here to note the general scheme of the new edition. The planetary and solar portions will remain untouched, saving the addition of new matter in foot notes. As it was felt that this was work that could be only satisfactorily done by specialists, Miss Brown was asked to look over the pages assigned to the Sun; Mr. A. Stanley Williams, Mercury, Venus, and Mars; Mr. Elger, the Moon; Mr. Waugh, Jupiter; Mr. Freeman, Saturn; Mr. Denning, Comets and Meteors—on which a short chapter will be added. Celestial Photography and Spectroscopic work will also have short chapters assigned to them. The work will be divided into two volumes, the first containing the Sun and Planets. The second volume will contain Double Stars, &c. This will be entirely re-written, and the objects arranged in each constellation in order of Right Ascension. The measurements and magnitudes of Struve will be substituted for those of the Bedford Cycle, as this work has been so ably re-edited by Mr. Chambers. It must be remembered that Prebendary Webb's scheme was a two-fold one: To give objects interesting from their motion and also to record remarkable groupings and colors. The work of selecting new objects was one of considerable difficulty; but it has been thought best to confine them to a definite magnitude, and this has been fixed by the brightness of the Primary. All double stars will, therefore, be included, whose Primary is above 6.5 mag. and whose distance is less than 20 seconds. Some new groupings and pairs of marked color will be inserted; but it is felt that in this respect, the former edition was fairly complete. By the end of the year the selection was completed, and the work of bringing up the whole of the places to 1900 for the first twelve hours was finished, while considerable progress had been made in those between 12 and 20. Much valuable assistance and many suggestions for the new edition have been received, and, besides those already mentioned, my thanks are due to Messrs. Ranyard, Sadler, Burnham, Schiaparelli, Perrotin, Leavenworth, Gore, and Captain Noble, and the Astronomical and Physical Society of Toronto.

The report contains considerable other work of various kinds showing that Director Espin has been busy during the last year.

Poole Brothers Celestial Handbook and Celestial Planisphere.—This new work is compiled and edited by Jules A. Colas and published by Poole Brothers of Chicago. The handbook contains 110 pages with a great number of fine illustrations. It is printed on heavy plate paper and is a neat specimen of the printer's art. The themes are: Introduction, constellations north of the zodiac, constellations of the zodiac, constellations south of the zodiac, old and new constellations in chronological order, names of the principal stars, principal binary stars, finest double stars, stars of known parallax, stars of greatest proper motion, shooting stars, comets, planets, and indexes with two large plates. The accompanying planisphere is on a heavy card board 23 inches by 18.5 inches. The movable circle which is a map of the constellations, stars, and other celestial phenomena is 19.5 inches in diameter with North Pole as center, and extends to the 50th degree south of the Equator. It shows stars down to, and including, the fifth magnitude. The boundaries of the constellations are plainly marked and auxiliary lines are given as aids for star-tracing. At another time, we will speak more at length of this very useful planisphere. There are some points of improvement that make it superior to any other we have seen.

Observational Astronomy is the theme of a book in quarto form, consisting of about 86 pages and is intended for beginners. Its author is Arthur Mee. It was published by Daniel Owen & Company, Cardiff, 1893. Price 2s. 6d.

The book is an attempt to work out a capital idea. It contains, for the amateur, much late and useful information. It is amply illustrated, but we are sorry to see, that much of this part of the work is inexcusably bad. We can not imagine any reason why an author of the apparent ability of Mr. Mee should be obliged to use so many poor illustrations.

Logarithmic Tables by Professor George William Jones of Cornell University is a book first issued in 1889, and the copy now before us is the fourth edition. It has been enlarged by the addition of twelve new tables, and the whole matter has been re-set, and it is really a new book. The tables are on large open pages and in very clear, easy type. The eighteen tables presented are as follows: Four-place logarithms, four-place trigonometric functions, logarithms of numbers, constants of mathematics, and of nature, weights and measures, addition-subtraction logarithms, sines and cosines of small angles, trigonometric functions, natural logarithms, prime and composite numbers, squares, cubes, square roots, cube roots, reciprocals, quarter-squares, Bessel's coefficients, binomial coefficients and errors of observation.

Professor Jones has prepared an excellent book, as far as it goes, and there is reason to believe that its tables are very generally accurate. He has taken great care to insure accuracy in every particular, and so far as we know he has succeeded admirably.

Astronomical and Physical Society of Toronto.—At the last meeting reported communications to the society were read from L. Neiston, Royal Observatory of Belgium, Dr. R. Ball of Cambridge, England, and Dr. M. A. Veeder. Mr. Veeder called attention to the fact that the outburst of Holmes' comet which occurred Jan. 16 was coincident with the appearance of an enormous sun-spot on the eastern limb of the Sun. He thinks the luminosity of comets' tails is due largely to electro-magnetic conditions and at the time mentioned they were marked in character. Reports of the committee on the astronomical day, of observations, and of brilliant meteors were made. The paper of the evening was read by Arthur Harvey; theme, the telescope, giving something of its history and its enlarged field of work in modern times.

New York Academy of Sciences.—Section of Astronomy and Physics. Minutes of the Meeting, 1893, March 6. The Section was called to order at 8:20 P. M., Professor Rees in the chair. A paper was read by Mr. C. A. Post on "A New Driving Clock for Equatorials." The apparatus described has been in successful operation for more than a year. It involves a new method of control (not electric), and a new differential slow motion for photographing. This slow motion can be applied in either direction without stopping the clock, or changing its rate.

Mr. Jacoby communicated the results of some measures made by him upon Mr. Rutherfurd's plates of β Cygni. These additional measures seem to confirm the existence of a large parallax for this star.

Professor Rees exhibited a photograph of a meteor trail, recently obtained by Mr. John E. Lewis, of Ansonia, Conn.   HAROLD JACOBY, Secretary.

PUBLISHER'S NOTICES.

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